U.S. Mines, Bureau of

Bulletin 138

DEPARTMENT OF THE INTERIOR
FRANKLIN K. LANE, SECRETARY
BUREAU OF MINES
VAN. H. MANNING, DIRECTOR

COKING OF ILLINOIS COALS

BY

F. K. OVITZ

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ILLINOIS COAL-MINING INVESTIGATIONS
COOPERATIVE AGREEMENT

[This report was prepared under a cooperative agreement with the Illinois State Geological Survey and the department of mining engineering of the University of Illinois]

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GOVERNMENT PRINTING OFFICE
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First edition. March, 1917.

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COKING OF ILLINOIS COALS.

By F. K. Ovitz.

INTRODUCTION.

In its endeavor to promote a more efficient use of coal the Bureau of Mines, in cooperation with the Illinois State geological survey and the University of Illinois, has undertaken an investigation of the coking of Illinois coals. The investigation was started by collecting from various sources the data regarding experiments already made by others; these data have been compiled and are presented herein.

The present methods of using coal seem wasteful. When coal is burned in furnaces for the generation of steam, only the heat generated by the fuel is utilized; possible by-products are not only lost but frequently are the source of the smoke nuisance. The volatile matter containing the tar and heavy hydrocarbon gases is difficult to burn completely in many furnaces, and its decomposition produces black smoke. When coal is coked in a by-product oven, the volatile matter is no longer a nuisance but, on the contrary, is the source of many by-products, including benzol, toluol, gas, tar, ammonia, and cyanogen, all of which increase the value that may be obtained from coal.

The coke that remains after the volatile matter has been driven off is a valuable fuel that can be used for almost all purposes for which bituminous coal can be used, and it is necessary for some metallurgical work. It has about the same heating value as anthracite coal. Because of its cleanness and its burning without smoke, it is well suited for domestic heating and the generation of steam in plants where smokelessness is demanded. The use of coke for these purposes would do much to eliminate smoke in cities. The best grades are regarded as essential in many metallurgical processes for reducing ores to their metals.

By-product coking in the United States during the past three years has increased greatly. When the ovens now in course of construction are completed, the total capacity of by-product ovens will be more than double what it was in 1913. This increase has led to a search for coals other than those now known to be available for use in by-product ovens. Tests with coals from the southern part of Illinois have indicated that coke from Illinois coal unmixed with other coals can be used for fuel purposes and that coke from mixtures of Illinois coal with low-volatile coking coal might be suitable for some metallurgical work. In the tests the yield of ammonia was larger than is obtained from Eastern[a] coal.

Evidently the development of methods by which good coke can be made from Illinois coals and the by-products recovered is a matter of high importance. Any investigation that will indicate how, by proper treatment, these coals can be made available to supply the market for coke and gas in the Middle West will increase efficiency in their use, and will aid in conserving the country's supply of high-grade coking coal.

SCOPE OF REPORT.

The first part of this report outlines the present factors in the problem of coking Illinois coals and points out the future prospects. The quality of coke from Illinois coals alone, and from mixtures of Illinois coals with low-volatile coals is described, and the uses for which the coke is suitable are discussed. The gas-making properties and the value of the coals for making by-products are noted. Desirable methods of preparation of the coals, the impurities in them, and the effect of the impurities on the value of the coals for coke and gas making are considered.

The second part of the report deals with the character of Illinois coals, their nature, physical properties, and chemical composition. The nonhomogenous structure of the coal, the variation in composition of different beds, and even of the same bed in different localities are pointed out. Those districts in which the coals contain the smaller amounts of impurities and are more favorable for coking are grouped together.

The last part describes the tests made and gives detailed results. The tests are considered under three classes—those with beehive ovens, those with by-product ovens, and those with gas retorts. The details are as complete as the material available permits. The results of a few tests of the coke for furnace or other use are given.

ACKNOWLEDGMENTS.

Work on this investigation was started by H. C. Porter, formerly chemist of the Bureau of Mines, who made a preliminary survey of the field in order to ascertain if sufficient work had been done to warrant collection of available data.

Especial acknowledgment is given to the companies and individuals who generously furnished valuable data in their possession. Without

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[a] The term "Eastern coal" as used in this bulletin refers to bituminous coal from the northern part of the Appalachian field.

their cooperation the collection of these results would not have been possible.

Results have also been taken from Government and State publications and from articles in technical journals. For various reasons it has not been considered advisable to refer to every source of information, but reference is made to facts previously published.

Thanks are due to O. P. Hood, chief mechanical engineer of the Bureau of Mines, for his practical advice, and to H. I. Smith, assistant mining engineer of the bureau, who suggested sources of information and otherwise aided in the work. Thanks are also extended to F. W. De Wolf, director of the Illinois Geological Survey, and to S. W. Parr and H. H. Stoek, professors in the University of Illinois, for information on Illinois coals and assistance in obtaining data.

DIVISION OF THE STATE INTO COAL DISTRICTS.

For the purpose of designating and grouping the coals, the State has been divided into eight districts as shown in figure 1. The districting adopted by the Illinois Coal Mining Investigations,[a] based on geographical location of the coals and on their physical and geological condition, is used.

The source of the coal is given by county, district, and bed, allowing a general grouping of the results of the tests without giving the names of the mines from which coal was taken. Although this method of designation seems to show that many of the tests cover the same coal, they actually represent different mines working the same bed in different parts of a county or district. In some tests, as those by the United States Geological Survey, the location of the mine is given as it has previously been published. The numbers designating the beds are those used by the Illinois Geological Survey.

The districts shown in figure 1 do not contain quite all the mines worked in the State, but 98.3 per cent of the tonnage is produced in them. In 1912 districts 7, 6, 4, and 5, ranking in the order named, produced 82 per cent of the coal of the State. Districts 2 and 3 each produced less than 1 per cent.

CHARACTER OF COKING PROCESS.

The coking of coal is a destructive distillation either in the absence of air or in the presence of a limited supply. In commercial practice coking is done in beehive and by-product ovens and in gas retorts. The methods of operation differ, as do the products obtained. Beehive and most by-product ovens are for producing metallurgical coke, whereas gas retorts are for obtaining illuminating gas. Coke from gas retorts is not as good as from coking ovens and is usually sold for domestic fuel.

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[a] Andros, S. O., Coal mining in Illinois: Illinois Coal Mining Investigations Bull. 13, 1915, p. 50.

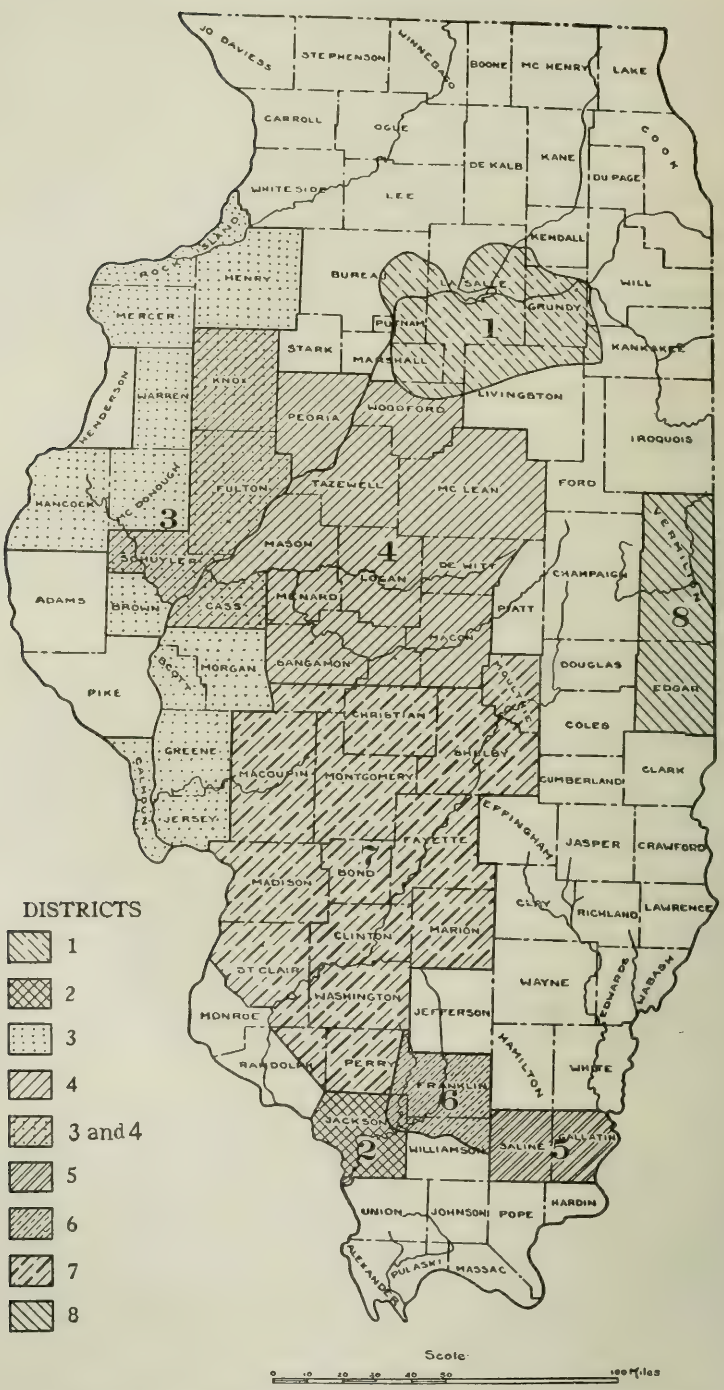

FIGURE 1.—Map of Illinois, showing coal districts adopted under the cooperative agreement.

In beehive ovens coke is ordinarily the only product obtained. The oven is heated from the inside by the combustion of gases driven from the coal and of part of the fixed carbon, a limited supply of air for this purpose being admitted through an opening in the side of the oven. A large share of the volatile matter is burned inside of the oven and the remainder, which passes out through the top, is burned when it comes in contact with air. Thus all the by-products are lost.

In by-product ovens coke is usually the principal product; gas, tar, ammonia, cyanides, benzol, and toluol can be recovered as by-products. The ovens are heated from outside by combustion of part of the gas obtained in coking. No oxygen comes into contact with the volatile matter to burn it and destroy the by-products, and the latter are separated from one another in a suitable recovery system.

In gas retorts illuminating gas is the principal product, coke and ammonia being by-products. The light oil, containing benzol and toluol, is left in the gas to increase its candlepower. The retorts are heated from the outside by combustion of part of the coke produced in the process or of coal. The units are of much smaller size than those used in coking ovens.

PRESENT CONDITIONS REGARDING COKING OF ILLINOIS COALS AND FUTURE PROSPECTS.

EXTENT OF COKE PRODUCTION.

So far as known, commercial coke is not at present being made from Illinois coal in either beehive or by-product ovens, although a small amount is made in gas retorts as a by-product from the manufacture of illuminating gas. Attempts to make commercial coke from Illinois coal in beehive ovens were abandoned, probably because the product could not compete with coke from other coals, and attempts to coke Illinois coal in by-product ovens have been experimental. The results indicate that with by-product ovens coke for fuel can be made from Illinois coal alone and that coke for some kinds of metallurgical work might be made from mixtures of Illinois coal with low-volatile coking coal. At some small gas plants Illinois coal alone is used in retorts for making gas; at other plants one-third Illinois coal and two-thirds Eastern gas coal are used, the gas from the two coals being mixed and the two grades of coke being kept separate.

QUALITY OF COKE.

In general, Illinois coke is light. The cells are not large, but are numerous enough to give a fairly high percentage of porosity. As the cell structure is irregular and the cell walls are thin, the coke is friable. When it is handled Illinois coke tends to shatter and form a large amount of breeze. Usually the coke comes from the oven in pieces of medium size which have a tendency to break into long fingerlike fragments and to become cross fractured. A characteristic feature is the presence of considerable nonfused material. The percentages of ash and sulphur are usually high. Available tests indicate that for a given purpose more coke from Illinois coal will be required than if coke from Eastern coal is used. The quality of coke made from Illinois coal is improved by mixing low-volatile coking coal with it.

METHOD OF JUDGING QUALITY.

The value of the coke from some of the coals was tested for certain purposes, but the coke from the majority of samples was judged by appearance and physical properties. As the relation between the results of physical tests of coke and its value in practical use is indefinite, different observers may differ widely in their opinions as to the suitability of a given coke for any purpose. Usually the tests made were conducted under operating conditions that gave satisfactory results with other coke, and without regard to any difference in the nature of the Illinois coke. The quantity of coke available was usually too small to permit tests to determine how far changes in practice would effect economy. If through the knowledge gained by experience methods of use could be changed to suit the coke, better results would probably be obtained.

COKE FROM BEEHIVE OVENS.

As is described in detail in a subsequent section, fairly good coke was produced in beehive ovens from some of the coals, whereas the coke from others was poor, and a few samples did not coke at all. The best cokes were light gray and silvery with a good cell structure. The pieces were of fairly large size, but were friable.

A few tests were made to determine the fitness of the coke for metallurgical use. Among these were the cupola tests by the United States Geological Survey [a] which demonstrated that the coke could be used in the foundry, but was not good as coke from Eastern coal. A trial run of about 24 hours was made in a blast furnace at the plant of a large iron and steel company. After four hours the furnace began to slip and became rather cold, and worked in this manner until all of the Illinois coke had been used.

COKE FROM BY-PRODUCT OVENS.

Most of the tests of Illinois coal alone in by-product ovens were made with the coals that had given the most promising results in beehive ovens. Therefore the quality of the coke from different by-product oven tests did not vary so much as did the coke from beehive-oven tests. The coke was not as strong as by-product coke from Eastern coals. The structure was fairly uniform, the cells were small and numerous, and the cell walls were thin. The coke had a tendency to break into pieces about 6 inches long and 1 or 2 inches in diameter. Some of it showed numerous cross fractures. When tumbled in a pile it gave a rustling sound and did not have a metallic ring. It contained considerable nonfused material.

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[a] Report of the United States fuel-testing plant at St. Louis, Mo., Jan. 1, 1906, to June 30, 1907: U. S. Geol. Survey Bull. 332, 1908, pp. 94, 113.

Coke made in by-product ovens from mixtures of Illinois coals with low-volatile coking coals was of better quality than that made from Illinois coals alone. The pieces were blocky, the coke was less friable, and the tendency to cross fracturing was somewhat reduced. Mixtures containing 20 per cent of Illinois coal gave better results than mixtures containing larger percentages.

USE OF ILLINOIS COKE IN METALLURGY.

Opinions as to the value of Illinois coke for metallurgical work differ. Most observers agree that it is not suited for use in large blast furnaces, but some think that it can be used in small furnaces, foundries, and smelters. Because of the cell walls being thin, it will not withstand the action of carbon dioxide nor bear the furnace burden as well as coke from Eastern coal. It has been used to some extent during periods when furnaces were slack, but without regard to efficiency, being consumed chiefly to maintain the supply of blast-furnace gas for power. A trial run made in a copper furnace demonstrated that the coke would carry the burden in a furnace of that type.

If absolutely necessary this coke could be used for some metallurgical purposes. It might be used at the present time if it could be sold at a considerably lower price than metallurgical coke from Eastern coal. Just what the difference in price must be can be determined only by a furnace test covering a considerable period of time. However, there are difficulties in the way of any considerable price reduction. The cost of mining coal is about the same as that of mining Eastern coal that makes highly satisfactory coke, but most Illinois coal requires washing, which adds to the cost.

DOMESTIC USE OF ILLINOIS COKE.

The most promising outlet for Illinois coke is as a fuel for domestic and other purposes not requiring coke of as high a grade as is necessary for metallurgical work. Thus, coke that will stand handling without too much loss by breakage can be used for practically all heating and power purposes for which bituminous coal is now used. Furthermore, a coke containing 2 per cent of sulphur will find as ready a sale for such purposes as one containing 1 per cent. The development of this trade to consume the output of several ovens would require considerable educational work, but once established there would be smaller fluctuations in the demand from year to year than in that for metallurgical coke, the consumption of which is dependent on the iron and steel industry. Producers of coke, by offering it at a reduced price, can induce many consumers of coke for domestic purposes to lay in a supply during the summer months and thus equalize demand. Work has already been started to develop the domestic trade in the Middle West and in the Northwest, with promising results. The high price of the domestic sizes of anthracite and the increasing opposition to the smoke nuisance are factors favoring the use of coke. With the enforcement of smoke ordinances in large cities like Chicago, the railroads will be forced to use coke on locomotives within the city limits or resort to electric power.

The importance of coal gas for lighting has increased recently because of the higher cost of making enriched water gas, caused by a higher price of the oil used in its manufacture. The oil problem is becoming serious with water-gas manufacturers and may cause a return to the use of coal gas. In that event the use of Illinois coals in by-product ovens in certain localities, with sale of the coke to the fuel trade, use of the gas for cooking and lighting, and recovery of by-products, would offer a promising field of development.

USE OF COAL IN GAS RETORTS.

At present a small amount of Illinois coal is used alone for making gas in some of the small plants where the cost of Eastern gas coal is too high. In other plants one-third of the retorts are charged with Illinois coal and the other two-thirds are charged with Eastern gas coal, the coke being kept separate.

Illinois gas coke is of poorer quality than gas coke from Eastern coals; it is light and porous, will not stand much handling, and is easily distinguished from Pittsburgh coke. Lengthening the time of carbonization seems to improve it somewhat. In places where competition is not keen it is sold to domestic trade and where competition is active it is used for heating retorts and for making water gas. In tests of Illinois coke with an 11-foot water-gas machine, owing to the formation of clinkers the capacity was reduced about 20 per cent in comparison with coke from Pittsburgh coal. The consumption of Illinois coke was about 10 per cent larger.

A yield of 4 to 4½ cubic feet of gas per pound of Illinois coal can be obtained, as compared with 5 or 5½ feet from Eastern coal. Gas from Illinois coal has a heating value of about 600 B. t. u. per cubic foot, and a candlepower of about 15. A larger quantity of gas can be obtained, but the excess is mostly hydrogen, which has no illuminating power and a low heating value per cubic foot. As city ordinances or State laws require illuminating gas to have a certain candlepower or heating value, it is advisable to stop carbonization before all of the lean gas is driven off. The low yield per pound increases the cost of manufacture, as more coal must be handled and a larger generating capacity provided to make the same amount of gas. As coal retorts are usually worked at their full capacity, any increase in output must be obtained from additional retorts, involving a larger investment.

If the quality and appearance of the coke could be improved, the author believes more Illinois coal would be used for making gas. The same coal makes better coke in by-product ovens than it does in gas retorts and at least part of the difference is due to methods of operation. If the coal were finely pulverized before charging, if the size of the charge were increased, and if the method of heating were similar to that used in heating by-product ovens, it seems possible that the quality of the coke could be improved without impairing the yield of gas.

GENERAL RESULTS OF USE OF MIXTURES OF ILLINOIS AND OTHER COALS FOR MAKING COKE.

The mixtures tested in by-product ovens ranged from 20 to 90 per cent Illinois coal with different varieties of low-volatile coking coal. In gas retorts results were obtained with the use of one-third Illinois coals in combination with several Eastern gas coals. The use of 20 to 30 per cent of Illinois coal mixed with a low-volatile coal for making metallurgical coke offers promise of success. Interest in this subject is active at present and the question of whether the use of such coke is profitable may be definitely answered in the near future.

RESULTS IN BY-PRODUCT OVENS.

Mixtures of low-volatile coking coal and Illinois coals make better coke than Illinois coals alone. The effect of the addition of 80 per cent low-volatile coal is well illustrated in Plates I, *B*, III, *B*, V, VI, VII, VIII, IX, and X.

The cell walls are stronger and there is less tendency to fingering and cross fracturing than in coke made from Illinois coals only. Compared to coke made from mixtures of Eastern coals it may have an advantage in one respect of Eastern coals—the cell walls being somewhat thinner a relatively larger percentage of surface is exposed to the action of oxygen, so that the coke burns more rapidly, the heat is generated in a small area, and the furnace drives faster. This property is desirable if combined with cell-wall strength sufficient to withstand the burden in the furnace. However, in general the addition of Illinois coal to Eastern coal should be considered an adulteration, and the question is, How much can be added without reducing the quality of the coke to the point where it can not be used for metallurgical work?

Coke from mixtures of 20 per cent Illinois coal and 80 per cent low-volatile coal has been used in blast furnaces for several consecutive weeks. No great trouble was experienced although there were some soft spots in the coke. As far as furnace operation is concerned, coke from such a mixture can be used. Possibly the proportion of Illinois coals can be increased to 30 per cent or more, but the use of even 20 per cent in all the by-product ovens near the Illinois coal field would mean a large annual consumption. There are more than 1,500 by-product ovens, with a capacity of about 9,000,000 tons of coal annually, within a short distance of this field.

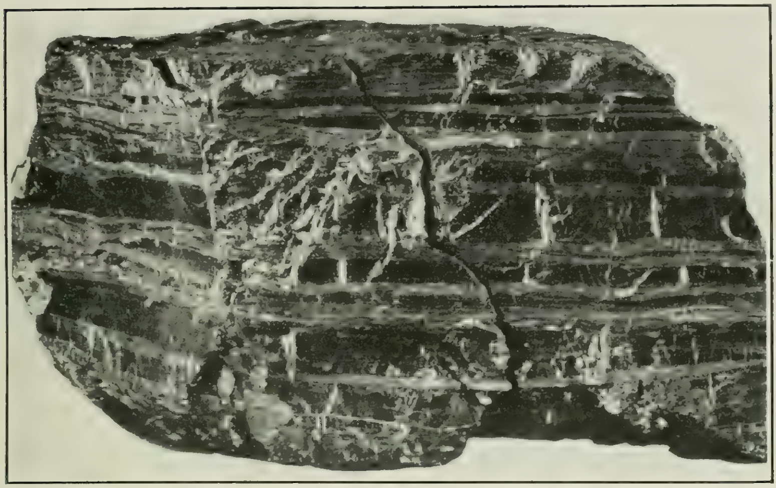
Naturally the principal incentive to use such a mixture would be a reduction in the cost of fuel for metallurgical work. Illinois coal is cheaper in the Middle West than the Eastern high-volatile coals it would replace, and, therefore, other factors being the same, coke could be made at a lower cost per ton. If the same amount of this coke as of coke from Eastern coals were required per ton of iron, the saving from the use of Illinois coal could be calculated. However, both known and unknown factors enter into the problem and as yet sufficient information has not been obtained to show just how much saving would result. The yield of coke is lower, and more coke is required per ton of iron produced, but to offset these disadvantages a larger quantity of by-products and more blast-furnace gas would be made. If it is shown that the use of coke made from mixtures containing 20 per cent of Illinois coal means a substantial saving, a considerable amount of such coke undoubtedly will be used.

By adding a low-sulphur Eastern coal to Illinois coal, coke of satisfactory sulphur content can be obtained. If 80 per cent of Eastern coal containing 0.7 per cent of sulphur is used, the 20 per cent of Illinois coal can contain about 2 per cent of sulphur without the sulphur content of the mixture running over 1 per cent. A large amount of Illinois coal contains less than 2 per cent of sulphur and hence would be available for use in such mixtures.

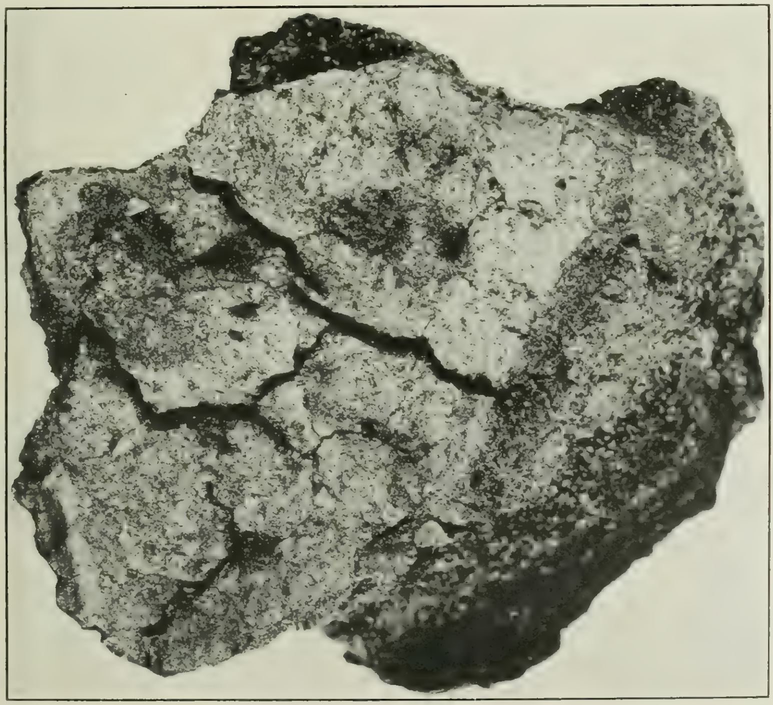
RESULTS IN GAS RETORTS.

The results obtained in gas retorts from the use of Illinois and Eastern coals in separate retorts have caused several plants to adopt such procedure. The plants have been able to show a reduction in cost of gas of about 2 cents per 1,000 cubic feet when one-third Illinois and two-thirds Eastern gas coal were used.

The gas and the by-products from the two sets of retorts go into the same recovery system, but the coke is kept separate. The quality of the gas is about the same as from Eastern coal alone and the yield is only slightly less. There is not much difference in the



A. LUMP OF SOUTHERN ILLINOIS COAL, FROM FRANKLIN COUNTY. SHOWS ALTERNATING LAYERS OF DULL AND SHINY APPEARANCE.



B. COKE FROM 20 PER CENT ILLINOIS (DISTRICT 6, BED 6) COAL AND 80 PER CENT LOW-VOLATILE COAL, TEST 10. BLOCKY PIECES, GOOD COLOR.

yields of tar and the ammonia, the former being slightly less and the latter slightly more than from Eastern coal alone. The coke from Illinois coal is used for heating retorts and making water gas, and that from the Eastern coal is sold for domestic use. If the coals were pulverized and thoroughly mixed instead of being charged into separate retorts, it is believed that all of the coke could be made suitable for the domestic trade. The cost of such preparation might be met by increasing the proportion of the cheaper Illinois coal.

EFFECTS OF VARIOUS FACTORS ON COKING OF ILLINOIS COALS.

USE OF HIGH TEMPERATURES.

There is a rather general opinion that high temperatures give better results in making coke from Illinois coal. Some investigators believe that high temperature combined with fine grinding is all that is necessary to produce from Illinois coal coke suitable for any metallurgical use. This possibility remains to be demonstrated, for the exact improvement by high temperature can be determined only by thorough investigation. The results of tests herein reported seem to indicate that high temperature does improve the quality, but the results are not complete enough for drawing a definite conclusion.

ADDITION OF PITCH.

Although no results of tests of making coke from Illinois coals with the addition of pitch are reported, a few such tests have been made. Adding about 5 per cent improves the coke. The cell structure is more open, and the tendency to cross-fracturing is reduced.

The addition of pitch to low-grade coking coals may furnish a profitable use for any excess supply of pitch resulting from the increased number of by-product ovens and may develop a market for a large quantity. The field invites investigation.

YIELD OF BY-PRODUCTS.

The yield of gas from by-product oven tests ranged from 11,000 to 13,000 cubic feet per ton (2,000 pounds) of coal, and in by-product laboratory tests averaged about 10,500 cubic feet per ton. Thirteen thousand feet is a high yield and probably could not be obtained in regular practice. The yield of gas from Illinois coals is slightly smaller than from high-volatile Eastern coals, but is larger than from low-volatile coals. When 20 or 30 per cent of Illinois coals are mixed with low-volatile coals the yield is about the same as from similar mixtures of Eastern coals.

More ammonia is obtained from Illinois coals than from Eastern coals. The maximum yield in by-product ovens was 34 pounds of ammonium sulphate per ton of coal, and the average was 26.6 pounds, equivalent to 6.8 pounds of ammonia (NH_3). The maximum yield by laboratory test was 41 pounds of ammonium sulphate per ton, and the average was 34.9 pounds. In gas retorts the high yield was 24.9 pounds of ammonium sulphate or 6.42 pounds of ammonia (NH_3). It is safe to say that a yield of 6 pounds of ammonia, or more than 23 pounds of ammonium sulphate, could be obtained in the regular operation of gas retorts. In some of the gas tests the quantity of ammonia was determined at the outlet of the exhauster and therefore is low, as considerable ammonia is absorbed before the gas reaches the exhauster.

The average yield of tar from by-product oven tests was 11.9 gallons per ton of coal, and by laboratory test was 7 gallons. Although few data were obtained for the tar from gas retorts, the yield is probably 10 to 12 gallons per ton, compared with about 15 gallons from Pittsburgh coal. The quality depends upon temperature and the consequent amount of cracking; in general, the tar from the Illinois coal compares well with other tars.

The laboratory tests gave an average yield of 18.9 pounds, or slightly less than 3 gallons, of light oil per ton of coal. Only laboratory determinations were made, and no results of oven tests are available for comparison. Consequently, it is difficult to predict how well the laboratory results will be confirmed in practice. At low temperatures the aromatic hydrocarbons are not formed to any great degree, and at high temperatures they decompose rapidly. Therefore, the laboratory test must reproduce closely the amount of cracking in the ovens in order to be of practical value.

EFFECT OF IMPURITIES IN COAL.

High sulphur and ash contents limit the use of Illinois coals for coking, as both coke and gas manufacturers desire coals as low as possible in sulphur. The customary specification for metallurgical coke is not more than 1 per cent of sulphur, which means that the coal can not contain much more than 1 per cent, as about half of the sulphur remains in the coke and the yield of coke, by weight, is 60 to 70 per cent. Sulphur must be removed from illuminating gas, and the more that must be removed the higher is the cost of purification. For this reason high-sulphur coal will not be used when low-sulphur coal can be obtained.

All of the ash in a coal remains in the coke. If a coal contains 10 per cent of ash and yields 60 per cent of coke, the coke will contain 16.6 per cent of ash. Ash does not fuse at coking temperatures; it increases the amount of nonfusible material that must be cemented by the fusible part of the coal and makes the fusion less uniform.

NEED OF WASHING ILLINOIS COALS.[a]

Most Illinois coals should be washed before coking in order to reduce the sulphur and the ash contents. A limited amount of Illinois coal has a sulphur content of about 1 per cent, but the average is higher. The coal from district 2, which contains less sulphur and ash than that from any other district, averages 1.29 per cent sulphur and 5.72 per cent ash. Ash contents of the coals from all the districts are given in Table 1 (p. 23). About 25 per cent of the sulphur and 20 to 30 per cent of the ash can be removed by washing or dry-cleaning. Part of the sulphur combined as iron pyrites can be removed, the proportion depending on whether the pyrite is in lumps or is disseminated in fine particles. In the latter form it can not be removed by washing, nor can organic sulphur be removed in that way.

Proper sizing of the coal is important. The impurities in the very fine coal can not be reduced much and for this reason the fines should be removed before washing. In selected coals the sulphur can be reduced to less than 1.5 per cent, and when these are used in mixture with low-sulphur Eastern coals, coke can be produced low enough in sulphur to meet metallurgical requirements.

Part of the ash is intimately mixed with the coal substance, is an inherent part of the coal, and can not be removed by cleaning. The remainder is from layers or seams of pyrites, shale, or other materials in the coal bed, which were mixed with the coal during mining. This part can be reduced by care in mining and by subsequent cleaning.

The cost of washing is 5 to 10 cents per ton, and 10 to 25 per cent of the coal is lost during the operation. The increase in the price of coal due to washing is shown by the following example. If the cost of washing is 5 cents per ton, and 15 per cent of the coal is lost, then with raw coal at $1 per ton the price of the washed coal would be as follows:

$$\frac{1.00+0.05}{0.85}=\$1.23 \text{ per ton.}$$

EFFECT OF CRUSHING COAL.

Tests in beehive ovens were made with both coarse and fine coal, and invariably the fine coal produced the better quality of coke. The reason is probably found in the nonhomogeneous character of Illinois coal. It is made up of layers, some of which fuse, whereas others do not, the nonfusible layers causing the weak spots in the coke. Fine crushing breaks up the nonfusible seams and pieces of slate so that they can be evenly mixed through the mass of coal. Thus, the small particles of nonfusible material are brought into close contact with fusible particles, become cemented during coking, and the coke is stronger and more uniform. Large pieces of unfused material give more chance for the coke breaking into small pieces. If there is too much nonfusible material, the particles will not be cemented and the coke will be granular. In order to get the best results in coking Illinois coals they should be crushed very fine.

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[a] For results of experiments in washing Illinois coal, see Lincoln, F. C., Coal washing in Illinois: Univ. of Illinois Eng. Exp. Sta. Bull. 69, 1913, 108 pp.

If more than one variety of coal is used, proper crushing is necessary, so that the different coals can be thoroughly mixed; otherwise the coke will not be uniform.

COKING PROPERTY OF ILLINOIS COALS.

Practically all Illinois coals will fuse to some degree. Just what material imparts the coking property is not known, and many explanations have been advanced. These have been based on different considerations—the original material from which the coal was formed, the process of coal formation, and the chemical composition and the physical character of the coal. Because of the extremely complex nature of coal and the difficulty of determining and identifying constituents, the real cause remains unknown and the explanations advanced are largely hypothetical.

Chemical analysis does not show whether a coal will make good coke. Noncoking and coking coals may have practically the same proximate and ultimate composition by analysis and yet the relative amounts of resinous, humic, and cellulosic materials may differ decidedly. Coals that coke contain a considerable amount of resinous material and have a relatively high percentage of available hydrogen and a low oxygen content. However, these characteristics indicate only that a coal may coke, and can not be relied on as a measure of coking quality. In the present state of our knowledge of coking the only safe method of determining what a given coal will do is by actual test in an oven.

ILLINOIS COALS AVAILABLE FOR COKE MAKING.

Most Illinois coals will make coke of some sort. In general, coals from districts 2, 5, and 6 (fig. 1), in the southern part of the State, make better coke than those from other districts. However, not all the coals from the districts mentioned will coke, and the only way of determining the coking property of coal from any mine is by proper test.

District 6 seems to be the most available and promising field in the State. It contains a rather large area of coal and produces about one-fifth of the total output of Illinois. The impurities in the coal from that district are lower than in the coal from the other districts, except district 2; the sulphur averages about 1.5 per cent and the ash considerably less than 10 per cent. Much of the coal is low enough in sulphur to produce coke that will meet metallurgical requirements for sulphur content, if the coal is mixed with low-sulphur coking coal. The coal is also used for the manufacture of illuminating gas, being used alone and with Eastern gas coals.

The coals from district 5 in composition and coking property are similar to the coals from district 6, but are higher in sulphur, and therefore not as well suited for coking and gas making. District 5 produces about 7 per cent of the coal output of the State.

By analysis the coal from district 2 is of better quality than any other coal in the State, being higher in fixed carbon and lower in ash and sulphur. It is used successfully for gas making in some small plants in Illinois and Missouri, and formerly was coked in beehive ovens in the vicinity of St. Louis. The district is small, produces only about 1 per cent of the coal mined in the State, and hence is not of great importance as a possible source of coking coal.

Tests of coals from other districts of the State show that although some of the coals make fairly good coke, most of them are so high in sulphur that the coke could only be used for fuel or domestic purposes. Some of these coals are equal in fusing property to those of district 6.

The work that has been done on coking Illinois coals should be regarded as preliminary. Knowledge of the mechanics of the coking process is still limited, and it is entirely possible that some comparatively small improvement in the process may give the proper combination to produce good coke from Illinois coals.

CHARACTER OF ILLINOIS COALS.

GEOLOGIC FEATURES.

Illinois coals are classed as bituminous and in degree of maturity are regarded as intermediate between the Eastern bituminous and the Western subbituminous coals. The productive beds are found in the Pennsylvanian series of the Carboniferous system. Beds 1, 2, 5, 6, and 7 are mined commercially, and are described in publications of the Illinois Geological Survey.[a]

PHYSICAL CHARACTERISTICS.

Illinois coals look like other bituminous coals, being composed of alternating shiny and dull layers. They are less friable than Pocahontas or New River coals and stand shipping fairly well. The fractures, although sometimes conchoidal, are usually along horizontal and vertical planes more or less at right angles to each other, so that the coals have a tendency to break into cubical pieces. On an average about 15 per cent of the total output is in lumps that pass over a 6-inch screen, and about 20 per cent will pass through a $\frac{1}{4}$-inch screen.

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[a] See Andros, S. O., Coal mining in Illinois: Illinois Coal Mining Investigations Bull. 13, 1915, 250 pp.

The Illinois coals are usually classed as free burning and noncoking, but when subjected to destructive distillation fuse into more or less coherent masses. Practically all of the coals fuse to some degree The coke from different coals varies somewhat, but, as stated, is generally light and friable.

The structure is shown in Plates I, *A*, and II. Plate I, *A*, showing a lump of Franklin County coal, indicates clearly its nonhomogeneous nature. Plate II shows a magnified section taken from near the center of the lump shown in Plate I, *A*. Here the black shiny layers are nearly uniform, but the dull layers are divided into very thin laminæ. This structure is fairly typical of southern Illinois coals

Reinhardt Thiessen,[a] assistant chemist of the Bureau of Mines has examined Illinois coals under the microscope and found that the shiny layers consist of fragments of "wood" and range from a few microns to several millimeters in thickness. The "woody" nature is readily discerned by examining sections across the grain. Most of the "woody" layers are highly resinous, and in some samples almost the entire "woody" component has disappeared, and little is left except the resinous material. The dull layers are generally thicker than the shiny ones and are composed largely of finely disintegrated material, or "débris." On closer examination they are found to be further divided into dull and shiny laminæ a fraction of a millimeter thick. As in the thicker layers, the shiny parts are of a "woody" nature and the dull parts are composed of disintegrated material.

Examination of a partly coked lump shows that the shiny layers possess the coking property and that the dull layers do not. Under the influence of heat the shiny parts fuse and swell, whereas the dull parts simply char and crack. Consequently fine crushing and thorough mixing of the parts that fuse and those that do not seems to be necessary in order to obtain the best results in coking. Further microscopic study of coal may lead to a better understanding of the causes of coking.

CHEMICAL CHARACTERISTICS.

Although Illinois coals are of the same general type, the composition of samples from different parts of the State varies. The proximate analyses of averages are given, by districts, in Table 1.[b] In interpreting them it must be remembered that ash and sulphur are incidental impurities in coal and vary locally. In any one mine the proportions of these elements may be quite different from the average for the district. For instance, some mines in district 6 yield coal that contains considerably less than the average of 1.53 per cent of sulphur.

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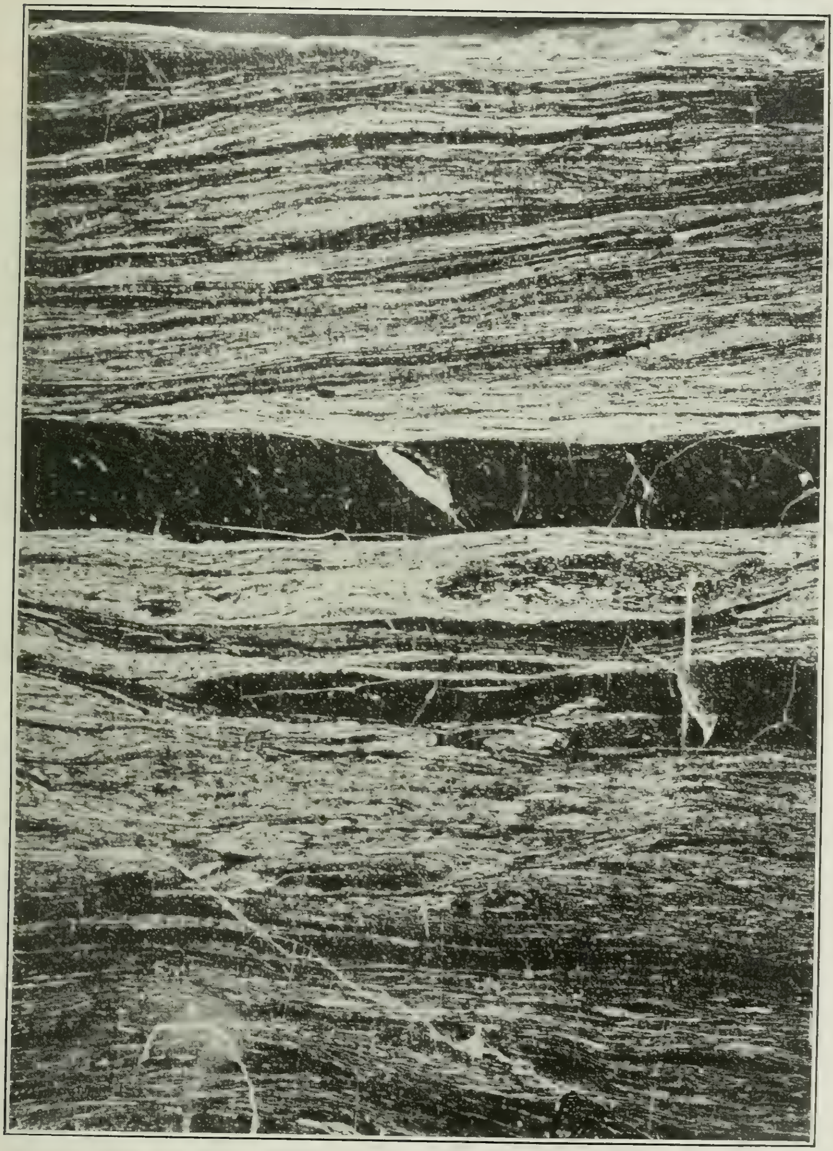
[a] See White, David, and Thiessen, Reinhardt, The origin of coal: Bull. 38, Bureau of Mines, 1913, p. 257

[b] Andros, S. O., Coal mining in Illinois: Illinois Coal-Mining Investigations Bull. 13, 191 , p. 57.



SECTION FROM NEAR CENTER OF LUMP OF COAL SHOWN IN PLATE I, *A*, MAGNIFIED 10 TIMES. SHOWS SUBDIVISIONS OF THE DULL LAYERS.

TABLE 1.—*Average analyses of Illinois coals arranged by districts.*[a]

District No.	Seam No.	Number of samples.	Proximate analysis of coal.[b]				Sulphur.	Heating value.	Heating value of unit coal.[c]
			Moisture.	Volatile matter.	Fixed carbon.	Ash.			
			P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*B. t. u.*	*B. t. u.*
1	2	33	16.18	38.83	37.89	7.08	2.89	10,981	....
			....	46.38	45.21	8.45	3.45	13,101	14,528
2	2	15	9.28	33.98	51.02	5.72	1.29	12,488	....
			....	37.46	56.24	6.30	1.42	13,765	14,818
3	1	11	15.58	30.17	35.80	9.45	4.69	10,673	....
			....	46.40	42.41	11.19	5.55	12,643	14,546
	2	3	17.40	33.30	41.48	7.82	2.03	10,811	....
			....	40.32	50.23	9.48	2.45	13,091	14,663
4	5	54	15.10	36.79	37.59	10.53	3.52	10,514	....
			....	43.33	44.28	12.40	4.15	12,384	14,447
5	5	27	6.75	35.49	48.72	9.04	2.92	12,276	....
			....	38.06	52.25	9.69	3.13	13,165	14,812
6	6	58	9.21	34.00	48.08	8.71	1.53	11,825	....
			....	37.45	52.96	9.59	1.68	13,025	14,585
7	6	76	12.56	38.05	39.06	10.33	4.01	9,848	....
			....	43.52	44.67	11.81	4.59	12,406	14,377
8	6	31	14.45	35.88	40.33	9.34	2.55	10,919	....
			....	41.94	47.14	10.92	2.98	12,764	14,557
	7	18	12.99	38.29	38.75	9.98	2.93	11,143	....
			....	44.01	44.53	11.47	3.37	12,807	14,740

[a] Analyses made by J. M. Lindgren under direction of Prof. S. W. Parr.

[b] Upper horizontal line of figures opposite each district number represents coal as received; lower line of figures represents moisture-free (or "dry") coal.

[c] "Unit coal" refers to the combustible organic material. The heating value on the unit-coal basis is obtained from the following formula: Unit B. t. u.$=\frac{\text{Dry B. t. u.}-5{,}000\ S}{1.00-(1.08A,+55S)}$, in which A is weight of ash per gram, and S is weight of sulphur per gram.

The fixed carbon varies from about 42 to 57 per cent on the dry-coal basis. The proportion of fixed carbon indicates in a general way the yield of coke that may be expected from a coal; that is, the higher the fixed carbon the greater the probable yield of coke. The fusibility and swelling when heated can be judged to some extent by examining the residue from a fixed-carbon determination, but this does not afford a criterion of the result of heating under other conditions.

The volatile matter ranges from about 37.5 to 46.5 per cent on a dry-coal basis. It is the source of gas, tar, ammonia, and other by-products. Parr[a] has shown that a large part of the volatile matter in Illinois coal is inert. Forty per cent of the volatile matter, or 14 per cent of the entire coal, is inert, as contrasted with 22 and 4.2 per cent in the case of Pocahontas coal and 47 and 21.63 per cent in the case of North Dakota lignite, and this fact should be given consideration in estimating the value of coal for gas making. When coal is carbonzied the inert volatile matter is driven off largely as water of decomposition, carbon dioxide, and nitrogen. These constituents are not combustible and reduce proportionately the quantity of useful gas that can be obtained.

The average sulphur content, by districts, varies from 1.42 to 5.55 per cent on the dry-coal basis. Some mines produce coal containing less than 1 per cent, but they are exceptions. The sulphur is combined less chiefly as iron pyrites (FeS_2); but part of it is combined with the coal substance in organic form. Also a small part is frequently combined as calcium sulphate, present in thin white flakes along the cleavage planes of the coal. When coal is coked approximately one-half of the sulphur is driven off in the volatile matter and one-half remains in the residue. All of that combined as sulphate remains in the coke.

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[a] Parr, S. W., Composition and character of Illinois coals: Illinois State Geol. Survey Bull. 3, 1906, 86 pp.

Ash in most Illinois coals is high, averaging about 10 per cent (dry-coal basis). It is largely an incidental impurity and varies in coals from different parts of a district and even in coal from different parts of the same mine. In the coking process all of the ash remains in the coke; therefore coke shows a higher percentage of ash than the coal from which it is made. High ash content is objectionable because the ash replaces an equal amount of combustible in the coke and correspondingly decreases the heating value. However, such increase of ash is more than offset by the removal of inert material. As pointed out on page 23, the inert volatile matter may amount to 14 per cent of the weight of Illinois coal, which, added to the moisture, may increase the noncombustible material, aside from the ash, to 25 per cent of the weight of the coal. Thus the coke is a more concentrated fuel than the raw coal, even though the coke has a higher ash content.

Phosphorus in Illinois coals is usually low. All of the phosphorus in coal is retained in the coke. As far as using the coke for metallurgical purposes is concerned, the proportion of phosphorus in Southern Illinois coal is not objectionable.

GROUPING OF COALS ACCORDING TO COMPOSITION.

In Table 2 following, the coals are arranged according to their fixed carbon content on the moisture-free and ash-free basis, the values for fixed carbon and volatile matter being obtained by calculation from the figures given in Table 1. The values for oxygen and available hydrogen are averages taken from ultimate analyses given in Bulletin 16 of the Illinois State Geological Survey.[a] No ultimate analyses could be obtained for samples from districts 2 and 3.

TABLE 2.—*Average analyses of Illinois coals arranged according to fixed carbon content on the moisture-free and ash-free basis.*

Fixed carbon.	Volatile matter.	Oxygen.	Available hydrogen.	Seam No.	District No.
Per cent.	*Per cent.*	*Per cent.*	*Per cent.*		
60.0	40.0	....	....	2	2
58.5	41.5	10.12	3.98	6	6
57.8	42.2	9.75	4.08	5	5
55.5	44.5	....	....	2	3
52.9	47.1	11.41	3.91	6	8
50.7	49.3	11.64	3.76	6	7
50.6	49.4	11.61	4.20	2	1
50.5	49.5	11.42	4.09	5	4
50.3	49.7	11.32	3.98	7	8
47.7	52.3	....	....	1	3

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[a] Parr, S. W., The chemical composition of Illinois coal: State Geol. Survey Bull. 16, 1910, pp. 203-243.

The table shows that fixed carbon and volatile matter vary considerably in samples from different parts of the same bed. For example, the samples from seam 2 in district 2 contained an average of 60 per cent of fixed carbon, whereas samples from the same seam in district 1 contained an average of 50.6 per cent fixed carbon. Hence the seam number is not a reliable guide to the composition and properties of any sample of coal from it. If coal from a certain bed in one locality produces coke, coal from the same bed in another locality will not necessarily produce similar coke.

Coal from districts 2, 5, and 6 contains more fixed carbon and less volatile matter than that from the other districts. There is an average decrease of more than 7 per cent in fixed carbon and a corresponding increase in volatile matter in the coal from these districts as compared with that from districts 1, 4, 7, and 8. Coal from districts 2, 5, and 6 is also lower in oxygen than that from districts 1, 4, 7, and 8. Although no ultimate analyses of coal from district 2 are available, it is quite likely that this coal is also low in oxygen, as the fixed carbon is high.

Districts 2, 5, and 6 comprise an area extending across the southern part of the State, including Jackson, Franklin, Saline, and Gallatin Counties and that part of Perry County east of the Duquoin anticline. The coals are somewhat similar in composition and differ considerably from the other coals of the State, being higher in fixed carbon and lower in oxygen, sulphur, and ash, and hence better suited for coking. These coals are more mature than the other coals of the State; that is, they retain less of their volatile constituents, as shown by the higher percentage of fixed carbon and the lower percentage of oxygen. In these respects they approach nearer to the good coking coals of the East, which are characterized by a relatively high fixed carbon and a low oxygen content. Just what relation exists between oxygen and the coking property is not understood, but seemingly high oxygen content in a coal tends to destroy the coking property. It has been shown on a laboratory scale that coal that has been heated to 120° C. for several hours in an atmosphere containing oxygen tends to become noncoking. It is generally believed that weathered coal produces poorer coke than freshly mined coal, and this belief may be justified by the fact that weathering is largely a slow oxidation of the coal substance.

As regards composition alone, the coals from the southern part of the State—districts 2, 5, and 6—are better suited for coking than the other coals. This statement is based upon the average composition by districts; certain coals in any one district may differ from the average, and therefore would not be included.

HISTORICAL REVIEW OF COKING OF ILLINOIS COALS.

Fairly satisfactory results were obtained in some of the early attempts to coke Illinois coals, and these excited strong hopes that the problem of local coke production had been solved.

TESTS REPORTED BY LUEBBERS.

In 1872 Luebbers [a] described a process of making coke from Illinois washed slack on a large scale, stating that although certain experiments under way were in their infancy the results were promising.

The ovens were built in the form of an arched culvert, 1½ to 6 feet wide and closed at either end by cast-iron doors, and the coke was pushed with a ram. The length of the ovens was not stated. The ovens were built in rows of 20 to 30. The coking time was 24 to 36 hours. The coke, which was somewhat porous, but sufficiently dense for use in blast furnaces, weighed about 38 pounds per bushel. The yield was about 60 per cent of the weight of the washed coal. No mention is made of the location of the ovens nor of the source of the coal used.

USE OF BEEHIVE OVENS AT MURPHYSBORO, ILL.

In about 1886 some beehive ovens were operated at Mount Carbon, near Murphysboro, Ill. They produced considerable coke, probably three or four hundred thousand tons. Some of it was used in near-by blast furnaces and some of it for reducing zinc ores in the Missouri district. The ovens were abandoned years ago and are at present in ruins. The coal used was from bed 2 in district 2.

EXPERIMENTS IN SANGAMON COUNTY.

Experiments by an iron company, a coal company, and a gas company are described in an article by Ridgely.[b]

The coal company was throwing away more than 500 tons of fine coal daily, and it proposed to coke this coal, from Sangamon County, to recover the tar and ammonia.

An experimental oven was tried, but the coke was not satisfactory. The company then undertook to use the coal in a by-product gas producer and recover ammonia and tar. All of the ammonia could not be recovered. Although as high as 45 pounds of ammonium sulphate per ton was obtained at times, this yield could not be maintained regularly. Altogether, four or five hundred tons of ammonium sulphate and about 5,000 barrels of tar were obtained. As the production was not economical the work was stopped and has never been resumed.

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[a] Luebbers, H. L., The manufacture of coke from Illinois coal: Trans. Am. Soc. Civil Eng., vol. 2, 1874, p. 163.

[b] Ridgely, Charles, An experiment with the by-products of coal: Illinois Min. Inst. Jour., vol. 3, 1894, p. 39.

OVENS AT EQUALITY, ILL.

About 1890, 24 ovens were constructed at Equality, Ill. The ovens were about 20 feet long, 5 feet high, and 20 inches wide. They were built in a row with a flue between each two ovens. Coke was made from coal from district 5, bed 5, for a number of years, but since about 1910 the ovens have been idle. Coke of good quality is said to have been produced, but a high sulphur content restricted its usefulness.

OVENS NEAR SPARTA, ILL.

Some years ago 102 ovens of similar type to those at Equality were erected near Sparta, Ill. It is understood they were built to make coke from slack coal from district 7, bed 6. The ovens were not used much, some of them never being fired. They are still standing but have been idle for years.

LEITER EXPERIMENTS IN SOUTH CHICAGO.

About 1899, Levi Z. and Joseph Leiter supplied the funds to enable experiments to be made by Joseph Heminway in a modified beehive oven invented by him. Several coals were tested in a single oven, with gratifying results, and later 24 ovens were built at Thirty-fourth and Iron Streets, South Chicago, where tests were made on a larger scale.

The ovens differed from the ordinary beehive type in being fitted with a fan for supplying hot or cold air over the surface of the coal. By this arrangement it was possible to obtain a higher temperature and better control in heating the ovens. Claims were made that coke could be produced from coals previously considered noncoking, that a considerable part of the sulphur could be eliminated, and that in 12 to 15 hours coke could be made equal to the usual 48 or 72 hour coke. The ovens could be equipped for saving by-products.

The process was owned by the Universal Fuel Co., which intended to issue licenses to operating companies, but no other ovens were ever built, so far as known. Coals from Ohio, Indiana, Illinois, Iowa, and Kansas were tested, and it was reported the coke made from them was suitable for metallurgical use. After about two years, operation of the ovens at South Chicago was discontinued. A description of the ovens and some of the results obtained have been given by Moss.[a]

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[a] Moss, R. S., Improved Heminway process: Mines and Minerals, vol. 21, 1901, p. 412.

OVENS IN ST. CLAIR COUNTY.

About 1902 five or six beehive ovens were built to make coke from St. Clair County coal. It was stated that the ovens were built because a suitable contract price could not be obtained for Eastern coke. After the ovens had been completed a satisfactory price was obtained and they were little used. The coke was used for burning lime and was said to be satisfactory for that purpose.

EXPERIMENTS NEAR HARRISBURG, ILL.

An experimental oven has been erected near Harrisburg, Ill., and various Illinois coals have been tried in it. Although the results have been sufficiently promising to warrant the expenditure of considerable money, and although it is claimed that coke can be made from Illinois coals, at present the process is still in the development stage.

Summers,[a] the inventor, believes that good coke can be made in this oven from coal regarded as noncoking. The oven consists of a retort through which the coal is caused to move continuously and a furnace for heating the retort. Coal is charged through a hopper at one end of the retort, and coke is discharged at the other end. The temperature increases from the charging end to the exit end and volatile matter that is driven off at low temperature is forced to pass through hot coal or coke, thereby being decomposed and depositing carbon, which cements the particles.

DETAILED RESULTS OF COKING TESTS OF ILLINOIS COALS.

SCOPE OF TESTS REVIEWED.

The detailed results of coking tests of Illinois coals presented in the following pages include results of tests at high temperatures in beehive and by-product ovens, in gas retorts, and in the laboratory. The results given include those obtained with Illinois coals alone, with mixtures of 20 to 90 per cent of Illinois coal with low-volatile coals, and with one-third Illinois coals used in combination with two-thirds Eastern gas coal. Some of the records of tests are complete enough to include figures for the yield of by-products, whereas others are incomplete and contain information on a particular part of the process only. In some tests the coke was used in a blast furnace, a cupola, or a water-gas generator, or as fuel for heating retorts and generating steam, but in most cases the quality was judged from physical properties and appearance. It is believed that the results given are sufficient to show, in a general way, the character of the results that have been obtained up to the present time.

The results of the coking of Illinois coals at low temperatures are not included. Low-temperature coking has been investigated by

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[a] Summers, L. L., U. S. patents 943609 and 943610, Dec. 14, 1909; U. S. patent 951786, Mar. 8, 1910.

Parr and others at the University of Illinois.[a] They obtained a solid residue, containing 18 to 22 per cent of volatile matter, which makes a smokeless fuel suitable for domestic purposes. In a suction gas producer it proved fully equal if not superior to anthracite. The tar contains 28 to 30 per cent of tar acids and gives promise of being suitable for wood preservation. Plans are under way for extending the experiments, to allow study of the process on a commercial basis.

DISTRIBUTION OF COALS TESTED.

Coals from districts 1, 4, 5, 6, 7, and 8 (fig. 1) are represented in the results of tests presented. Table 3 gives the number of coals tested in each kind of oven and the district and seam from which each coal was obtained. Most of the tests were made with southern Illinois coals, especially those from district 6. No results of tests of coals from districts 2 and 3 are given. Coal from district 2 is being used successfully for manufacturing illuminating gas and would undoubtedly give as good results as any Illinois coals in by-product ovens. However, the possible output is small and therefore it does not offer much of a field for development.

TABLE 3.—*Distribution of coals tested.*

District No.	Seam No.	Number of coals tested in—		
		By-product ovens.	Beehive ovens.	Gas retorts.
1	2	2	....	....
	7	1	....	....
4	5	2	1	....
5	5	5	1	1
6	6	32	9	5
7	6	1	12	....
8	6	1	....	....

AVAILABLE DETAILS OF TESTS.

The results of tests have been collected from various sources. The conditions under which they were run were different and it was impossible to obtain details of some of the tests. Methods of sampling and analyzing the products and preparing the coal differed, as did the temperatures of carbonization, and in many instances complete information on these points could not be obtained. The results are not all stated on the same basis. For example, in some of the tests the analysis of coal and coke and the yield of coke are given on the dry basis, and in others they represent coal "as received;" or the figures for gas may not have been reduced to the same conditions of temperature and pressure in all cases. For these reasons care should be used in comparing the figures and too much reliance should not be placed upon the results of a single test.

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[a] See Parr, S. W., and Olin, H. L., The coking of coal at low temperatures: Univ. of Illinois Bull. 60, 1912, 46 pp.; Parr, S. W., and Olin, H. L., The coking of coal at low temperatures, with special references to the properties and composition of the products: Univ. of Illinois Bull. 79, 1915, pp. 29–30; Parr, S. W., and Francis, C. K., The modification of Illinois coal by low-temperature distillation: Univ. of Illinois, Bull. 24, 1908, 48 pp.

Observations on the tests are not uniform and information as to some tests is brief. When possible, all of the information available has been included in tables. In some cases the tests are treated individually, because of lack of uniformity in the information and the difficulty of including in the tables all the data available.

TESTS IN BEEHIVE OVENS.

OVENS AT SESSER, ILL.

Two experimental beehive ovens were built by a coal company at Sesser. The ovens were both 12 feet in diameter, one of them being 6 feet 3 inches high and the other 7 feet 3 inches high. Several tests were made of lump and run-of-mine coal, and of screenings from the company's mine, district 6, seam 6, including tests of charges of uncrushed and of finely crushed coal. The weights varied from 5 to 6½ tons and the time of coking from 34 to 82 hours.

As a result of the tests the opinion was stated that coke of good quality, suited for any commercial use, could be made from this coal. Washing was necessary for the run-of-mine coal and the screenings, and was recommended for the lump coal. Fine crushing was necessary in order to decrease the effect of unfused material in coke made from unwashed coal. The yield of coke was about 57 per cent. The same coal was tested by the United States Geological Survey, the results being given in Table 4.[a] It has also been tested in by-product ovens.

COKING TESTS MADE BY UNITED STATES GEOLOGICAL SURVEY.

Before the establishment of the Bureau of Mines the United States Geological Survey made coking tests in beehive ovens of coals from different parts of the country. From 1904 to 1907 the work was carried on at St. Louis, Mo. In 1907 the equipment was transferred to Denver, Colo., where work was continued until the summer of 1909. The testing of fuels was subsequently transferred to the Bureau of Mines, and the results of the work have been published in bulletins of the Geological Survey[b] and the Bureau of Mines.[c]

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[a] See results for Denver Nos. 15A and 15B (p. 34).

[b] Stammler, F. W., Coking tests: U. S. Geol. Survey Prof. Paper 48, pt. 3, 1906, p. 1326; Belden, A. W., Coking tests: U. S. Geol. Survey Bull. 290, 1906, p. 38; Belden, A. W., Coking tests: U. S. Geol. Survey Bull. 332, 1908, p. 32; Moldenke, R., Belden, A. W., Delamater, G. R., Washing and coking tests of coal and cupola tests of coke: U. S. Geol. Survey Bull. 336, 1908, p. 18.

[c] Belden, A. W., Delamater, G. R., Groves, J. W., and Way, K. M., Washing and coking tests of coal, at Denver, Colo., July 1, 1908, to June 30, 1909: Bull. 5, Bureau of Mines, 1910, 62 pp., 1 fig.

During this time 45 coking tests were made of 20 different Illinois coals. The tests at St. Louis were made in a battery of three beehive ovens of standard size and shape. Most of the tests were made in the two end ovens. After the first few tests the bottom of one of the end ovens was raised 8 inches in order to bring the charge nearer the dome and effect a more rapid penetration of heat. The tests at Denver were made in a battery of two beehive ovens, 12 feet in diameter, one being 7 feet high, the other 6 feet 3 inches.

The coal charged to the ovens was passed through rolls which reduced it to 1½ inches or smaller in the tests of Illinois No. 1 to Illinois No. 5 coals; in the other tests, unless otherwise stated, the coal was crushed so that practically all of it passed through a 10-mesh sieve. The weight of charges and the coking time were varied with the same coal and the effect of these changes upon the quality of the coke was noted.

A brief summary of these tests is given in Table 4. More detailed information is given in the bulletins cited. The designation of the coals is that used by the United States Geological Survey and the Bureau of Mines.

The analyses of coals are on the basis of coal as charged. Moisture in the washed coal is often higher than in the coal "as received," some water being retained from the washing process.

The analyses of coke are on the "as-received" basis, and the results include moisture from water used in quenching.

The yield of coke is based on the weight of coal as charged to the oven, so that owing to the high moisture content in some of the coals, the percentage yield of coke calculated in this way is low.

The item "coke" includes everything that remains after thorough shaking on a fork having tines 1½ inches apart.

The item "breeze" includes everything that will pass through a fork having tines 1½ inches apart. Its percentage is higher than from regular operations.

TABLE 4.—*Results of coking tests made by United States Geological Survey.*

Description of coal.				Results of analysis of coal and coke.							Yield of coke, per cent.			Physical properties of coke.						
Designation.	Source.	Size as shipped.	Kind of coal.	Sample.	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Phosphorus.	Coke.	Breeze.	Total.	Specific gravity.		Per cent by volume of—		Weight per cubic foot, pounds.		Remarks on coke.
														Apparent.	Real.	Coke.	Cells.	Dry.	Wet.	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Illinois No. 1	O'Fallon, St. Clair County, Ill., district 7, seam 6.	Lump and nut.	Raw	Coal	10.46	36.11	37.48	15.95	4.14											Small pieces of coke and charred coal.
				Coke																
Illinois No. 2	do	Slack	Washed	Coal	17.20	35.77	37.84	9.19	3.03											Coke not uniform, hard and soft mixed.
				Coke	1.57	2.83	75.42	20.18	2.75	0.030	37.6	3.9	41.5		1.87	48	52	50.2	82.5	
Illinois No. 3	Marion, Williamson County, Ill., district 6, seam 6.	Run of mine.	Raw	Coal	8.25	30.22	50.94	10.59	1.45											No coke.
				Coke																
			Washed	Coal	9.52	32.05	52.57	5.86	1.41											Fingered and brittle.
				Coke	6.11	.42	82.55	10.92	1.13	.019	49.1	6.4	55.5		1.84	45	55	46.7	80.9	
			do	Coal	17.86	31.65	32.93	17.56	3.25											No coke.
				Coke																
Illinois No. 5	Collinsville, Madison County, Ill., district 7, seam 6.	Slack	Rewashed	Coal	25.15	28.68	36.99	9.18	2.71											Do.
				Coke																
			do	Coal	14.60	30.76	36.48	18.16	3.44											Do.
				Coke																
Illinois No. 7-D	do	Run of mine.	Raw	Coal	10.88	35.27	38.44	15.41	4.53											Good hard coke; sulphur and ash high.
				Coke	2.26	1.86	72.68	23.30	3.95		48.8	5.7	54.5	0.85	1.91	45	55	51.8	86.1	
			Washed	Coal	12.45	36.17	42.08	9.30	3.64											Good strong coke, light-gray color.
				Coke	1.04	.61	82.10	16.25	3.24		52.0	2.6	54.6	.82	1.85	44	56	50.6	85.5	
Illinois No. 11-D.	Carterville, Williamson County, Ill., district 6, seam 6.	No. 3	do	Coal	8.24	31.64	52.81	7.31	1.55											Good strong coke, light gray and silvery color.
				Coke	1.19	.93	85.97	11.91	1.44	.007	54.0	3.0	57.0	.82	1.87	44	56	50.1	85.1	
Illinois No. 13	Benton, Franklin County, Ill., district 6, seam 6.	Through 6-inch, over 1½ inch screen.	Raw	Coal	10.56	30.08	49.08	10.28	1.71											Coke soft with dull appearance.
				Coke	2.73	1.36	79.30	16.61	1.77	.016	44.7	11.1	55.8	.90	1.90	47	53	54.6	87.7	
			Washed	Coal	11.44	30.95	50.16	7.45	1.25											Good hard coke, improved by washing.
				Coke	4.60	1.68	82.08	11.64	1.27	.007	46.0	7.2	53.2	.84	1.85	46	54	50.0	83.7	

Illinois No. 16	Herrin, Williamson County, Ill., district 6, seam 6.	Lump and egg.	do	Coal	9.79	30.35	51.79	8.07	1.09											Dull-gray color. Poor coke physically.
				Coke	2.14	1.46	83.96	12.44	1.02	.008	55.8	9.1	64.9	.87	1.85	47	53	53.1	86.2	
Illinois No. 19-A	Zeigler, Franklin County, Ill., district 6, seam 6.	¾-inch	Raw	Coal	12.79	27.24	51.73	8.24	.49											No coke produced.
				Coke																
			do	Coal	9.64	30.68	50.22	9.46	.53											Do.
				Coke																
Illinois No. 19-B	do	3-inch	do	Coal	10.72	29.77	49.30	10.21	.47											Do.
				Coke																
Illinois, No. 20	Staunton, Macoupin County, Ill., district 7, seam 6.	Screenings	do	Coal	17.04	32.59	40.77	9.60	3.23											Dull gray color; dense; cross fracture bad.
				Coke	.57	.66	82.49	16.28	3.01		42.6	6.3	48.9	.90	1.85	49	51	55.8	87.6	
			Washed	Coal	14.36	34.61	42.63	8.40	3.23											Dull gray color; a little better than from raw coal.
				Coke	.53	.29	84.87	14.31	2.72		46.6	4.0	50.6	.84	1.82	46	54	52.1	85.8	
Illinois, No. 21	Troy, Madison County, Ill., disrict 7, seam 6.	Lump	Raw	Coal	13.37	31.17	43.15	12.31	1.46											Slightly fused coal; no cell structure.
				Coke																
			Washed	Coal	17.45	30.01	44.74	7.80	1.10											Slightly fused coal; no coke.
				Coke																
Illinois, No. 22-B	Maryville, Madison County, Ill., district 7, seam 6.	Through 2-inch screen.	Raw	Coal	11.98	33.87	37.72	16.43	4.74											Poor coke; dull color; irregular breakage.
				Coke	.98	.72	72.18	26.12	4.61		50.5	5.3	55.8	.98	1.89	52	48	60.5	90.5	
			Washed	Coal	16.19	34.14	39.53	10.14	3.79											Poor coke; heavy; black ends.
				Coke	.65	1.60	80.76	16.99	3.65		46.8	4.8	51.6	.89	1.84	48	52	55.2	87.6	
Illinois, No. 23-A	Donkville, Madison County, Ill., district 7, seam 6.	Lump	do	Coal	13.74	36.47	41.01	8.78	3.57											Good heavy coke; ash and sulphur high.
				Coke	.66	.74	83.45	15.15	3.09		42.1	3.5	45.6	.79	1.85	43	57	48.9	84.5	
Illinois, No. 23-B	do	Slack	do	Coal	15.85	35.02	40.57	8.56	3.27											Do.
				Coke	.96	1.14	82.66	15.24	2.87		44.1	3.9	48.0	.79	1.81	44	56	48.8	83.7	
			do	Coal	15.93	35.88	40.16	8.03	3.25											Not as good as from No. 23-A coal.
				Coke	1.36	1.19	82.83	14.62	2.84		46.0	4.3	50.3	.85	1.86	46	54	52.3	86.0	
Illinois, No. 24-A	New Baden, Clinton County, Ill., district 7, seam 6.	Screenings	Raw	Coal	13.28	29.93	39.03	17.76	4.05											No coke.
				Coke																
			Washed	Coal	15.18	32.13	43.46	9.23	3.07											Do.
				Coke																
Illinois, No. 24-B	do	Lump	do	Coal	8.93	35.22	46.29	9.56	3.41											Poor soft coke.
				Coke	5.62	1.64	79.01	13.73	2.97		39.8	11.4	51.2	.93	1.80	52	48	54.7	84.7	
Illinois, No. 25	Germantown, Clinton County, Ill., district 7, seam 6.	Run-of-mine and lump.	Raw[a]	Coal	12.96	33.01	39.60	14.43	4.09											No coke.
				Coke																
			Washed	Coal	13.40	33.83	43.66	9.11	2.99											Soft dense coke.
				Coke	2.71	4.67	77.69	14.93	2.32		45.3	6.0	51.3	.88	1.89	47	53	53.4	86.5	
Illinois, No. 26	Lincoln, Logan County, Ill., district 4, seam 5.	Run-of-mine	do	Coal	15.18	33.46	41.53	9.83	2.73											Do.
				Coke	5.27	3.35	75.98	15.40	2.80		49.8	10.6	60.4	.89	1.80	49	51	52.6	84.4	
Illinois, No. 27	Auburn, Sangamon County, Ill., district 7, seam 6.	do	do	Coal	16.39	34.26	41.57	7.78	3.22											Soft coke; poor cell structure.
				Coke	3.51	1.55	81.14	13.80	3.40		43.9	3.5	47.4	.84	1.82	46	54	50.6	84.2	
Illinois, No. 28-C	Herrin, Williamson County, Ill., district 6, seam 6.	Lump	do	Coal	9.37	30.38	53.36	6.89	1.09											Poor coke.
				Coke	2.82	.60	86.12	10.46	.98	.008	50.4	5.3	55.7	.86	1.83	47	53	52.1	85.2	

[a] Charged as run-of-mine coal.

TABLE 4.—*Results of coking tests made by United States Geological Survey*—Continued.

Description of coal.				Results of analysis of coal and coke.							Yield o coke, per cent.			Physical proportios of coke.						
														Specific gravity.		Per cent by volume of—		Weight per cubic foot, pounds.		
Designation.	Source.	Size as shipped.	Kind of coal.	Sample.	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Phosphorus.	Coke.	Breeze.	Total.	Apparent.	Real.	Coke.	Cells.	Dry.	Wet.	Remarks on coke.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Illinois, No. 29-A.	Livingston, Madison County, Ill., district 7, seam 6.	Screenings	....do......	Coal.....	15.63	33.88	42.81	7.68	3.13	......	....	....	....	....	....	....	....	....	....	Poor dense coke.
				Coke....	.72	.90	84.62	13.76	2.57	......	41.2	5.7	46.9	.78	1.83	43	57	48.3	83.9	
			....do......	Coal.....	18.39	32.87	41.53	7.21	3.06	......	....	....	....	....	....	....	....	....	....	Poor coke.
				Coke....	2.78	.74	83.35	13.13	2.49	......	42.4	2.9	45.3	.80	1.83	44	56	48.5	83.5	
Illinois, No. 34-B.	Harrisburg, Saline County, Ill., district 5. seam 5.	Run of mine.	....do......	Coal.....	9.91	33.33	50.65	6.11	1.75	......	....	....	....	....	....	....	....	....	....	Good coke, sulphur high.
				Coke....	.19	.35	87.91	11.55	1.48	.021	50.3	2.4	52.7	.78	1.85	42	58	48.6	84.7	
Denver, No. 15-A	Sesser, Franklin County, Ill., district 6, seam 6.	....do......	Raw........	Coal.....	7.65	33.97	49.60	8.78	.91	......	....	....	....	....	....	....	....	....	....	Good coke, cell structure and breakage good.
				Coke....	2.52	2.20	79.63	15.65	.86	.020	61.4	3.4	64.8	.83	1.83	46	54	50.5	84.2	
			Washed.....	Coal.....	9.97	34.82	48.70	6.51	1.01	......	....	....	....	....	....	....	....	....	....	Good cell structure, some soft coke on bottom of oven.
				Coke....	1.02	1.58	87.38	10.02	.80	.017	56.6	4.0	60.6	.76	1.78	43	57	46.9	82.5	
			....do......	Coal.....	9.74	34.70	49.35	6.21	.97	......	....	....	....	....	....	....	....	....	....	Good cell structure, somewhat fingered.
				Coke....	.61	1.79	86.77	10.83	.81	.017	53.4	3.3	56.7	.77	1.77	44	56	47.7	82.6	
			....do......	Coal.....	5.32	38.43	49.42	6.83	1.02	......	....	....	....	....	....	....	....	....	....	Good coke, somewhat fingered.
				Coke....	.66	1.76	86.44	11.14	.71	.015	54.6	3.8	58.4	.78	1.79	44	56	48.4	83.3	
			....do......	Coal.....	9.23	35.64	48.30	6.83	1.00	......	....	....	....	....	....	....	....	....	....	Do.
				Coke....	.51	1.80	87.17	10.52	.78	.017	58.3	4.0	62.3	.82	1.79	46	54	50.9	84.5	
Denver, No. 15-B	.....do...........	Screenings..	....do......	Coal.....	11.19	35.11	47.27	6.43	.97	......	....	....	....	....	....	....	....	....	....	Good coke. Pieces of uniform size.
				Coke....	.55	1.40	87.44	10.61	.80	.017	50.7	3.0	53.7	.81	1.78	46	54	50.3	83.9	
			....do......	Coal.....	21.01	29.31	41.54	8.14	.90	......	....	....	....	....	....	....	....	....	....	Good coke, somewhat fingered.
				Coke....	1.54	2.14	80.55	15.77	.93	.021	46.8	3.7	50.5	.77	1.80	43	57	47.3	82.8	
			....do......	Coal.....	14.89	31.95	45.73	7.43	.87	......	....	....	....	....	....	....	....	....	....	Do.
				Coke....	2.27	4.81	78.73	14.19	1.04	.020	48.6	4.2	52.8	.81	1.79	45	55	49.4	83.7	
			....do......	Coal.....	7.79	32.56	50.35	9.30	.91	......	....	....	....	....	....	....	....	....	....	Good coke, somewhat fingered but uniform size.
				Coke....	.24	1.20	82.70	15.86	.81	.015	56.8	3.0	59.8	.86	1.80	48	52	53.5	86.0	

TESTS OF FRANKLIN COUNTY COAL AT REPUBLIC, PA.

The following information is taken from the report of a test of coal from Franklin County, district 6, seam 6, made by a large iron and steel company. The coal was coked in the company's beehive ovens at Republic, Pa., and the coke was tested in the company's blast furnace at Sharon, Pa.

COKING TESTS.

Ten single-row ovens were set aside for the test, the ovens being in good condition at the time of starting. First, the ovens were charged with run-of-mine coal. The coke resulting was practically worthless for blast-furnace use. Next, the ovens were charged with crushed coal and burned 72 hours. No great difference could be noticed in the coke so made. The ovens were then charged with crushed coal, wet, as though it had gone through a washer. The wetting appeared to tamp the coal in the oven and a heavier and denser coke was produced, the cells being much smaller than those in the coke made from dry coal.

A summary of the results of the coking tests follows:

Summary of results of coking tests of Illinois coal at Republic, Pa.

Total amount of coal charged, tons	438.19
Total amount of coke made, tons	224.30
Duration of test, days	16
Coal charged per day, tons	27.38
Coke made per day, tons	15.26
Tons of coal to net tons of coke	1.90
Total ovens drawn	70
Coal charged per oven, tons	6.25
Coke made per oven, tons	3.20
Yield of commercial coke, per cent	51.19
Yield of coke and refuse, per cent	57.25
Average temperature of ovens, °F	2,546

Average results of analyses of coal and coke.

	Coal.	Coke.
Volatile matter, per cent	....	2.84
Fixed carbon, per cent	....	83.62
Ash, per cent	7.31	13.54
Sulphur, per cent	1.26	1.15
Phosphorus, per cent	.008	.0115

CONCLUSIONS.

The following conclusions, based on the results of the tests, were drawn:

The coal would not make satisfactory coke without crushing.

The best coke from the test was obtained from coal crushed so that it would pass through a screen in which the holes were not greater than $\frac{3}{16}$ inch in diameter.

A heavier and denser coke was made by wetting the coal.

The best way to coke this coal was to start the ovens with heavy draft, gradually closing the draft as the oven was burned off. Driving the volatile matter off quickly gave a harder and better colored coke.

The average tonnage per oven, 12 feet 6 inches diameter, was not over 4 tons of coke.

The yield of coal to coke was 10 per cent less than the average yield obtained from Connellsville coal.

The coke could probably have been improved if the coal had been washed, so as to reduce the ash and sulphur contents.

USE OF COKE IN BLAST FURNACE.

The coke was found to be porous and of low specific gravity, weighing about 14.2 per cent less than the coke generally used. Although it did not look soft and had a fair structure, it acted in the furnace as if it did not have much strength, and when it was unloaded and handled, it broke into small blocks. The Illinois coke was started in the furnace on the twentieth round, day turn, December 16, and its use continued until the first round of the night turn of December 17, or 159 rounds. At the same time a change was made in the lime charged, to allow for the difference in composition of this coke. After the coke had been used about four hours the furnace began to slip, became somewhat cold, and worked in this manner until all the Illinois coke had been used.

COKING TESTS AT LINTON, IND.

In about 1908 four coking tests were made by a coal and coke company at Linton, Ind., of different sizes of coal from Franklin County, district 6, seam 6. They were made in a battery of 10 beehive ovens, which were 12 feet in diameter and 8 feet high. There were no scales at the plant and the yields given are calculated on railroad weights. The sampling and analyzing were done carefully and as accurately as was possible.

All the coal coked well and ignited quickly in the ovens. The coke from the screenings showed that they should be washed to improve the quality. The average yield of coke from the coal as charged was about 52 per cent. Breeze, including ash, was 6.7 per cent. Data regarding the tests are given in Table 5 following:

TABLE 5.—*Results of coking tests of Franklin County coal at Linton, Ind.*

Test. No.	Size of coal.	Number of ovens charged.	Weight of coal charged.	Weight of coke produced.	Yield of coke.	Time of burning.	Time of ignition.	Results of analysis.						
								Kind of sample.	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Phosphorus.
			Lbs.	*Lbs.*	*P. ct.*	*Hrs.*	*Min.*		*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
1	Run of mine..	10	90,000	46,100	51.2	45.5	27	Coal...	1.10	37.27	51.50	10.13	1.55	......
								Coke..	1.37	.76	82.85	15.02	1.13	0.012
2	2-inch screenings.	9	81,000	42,100	52	45	10	Coal...	8.06	33.16	47.80	10.98	1.16	.014
								Coke..	1.87	2.02	79.42	16.69	1.23	.013
3	Egg..........	10	....	....	......	60	4.5	Coal...	7.65	34.80	48.48	9.07	1.25	.007
								Coke..	1.75	.37	83.14	14.74	.90	.010
4	.....do.......	9	242,200	127,900	52.4	72	17	Coal...	7.50	34.24	48.12	10.14	.94	.011
								Coke..	1.94	1.01	81.22	15.83	1.12	.021

TESTS IN BY-PRODUCT OVENS.

Most of the tests in by-product ovens were made on a large scale under actual operating conditions. They were carried on during regular operation by charging one or more ovens with test coal. A few "box" tests were made, as follows: About 500 pounds of coal were put in a suitable container and placed in an oven. The yield and the quality of coke produced could be determined, but in most cases it was not possible to determine the yield of by-products. These passed into the regular recovery system and mixed with the products of distillation from the other ovens in the battery.

In most of the tests the by-products were determined in the laboratory. Laboratory tests usually show higher results than those obtained in commercial practice, and the results should not be compared directly with oven yields unless the method has been correlated with practice; even then it may be necessary to apply a correction factor. Conditions in the laboratory are more uniform and can be controlled better than in the ovens; therefore the laboratory test can be used as a guide to determine whether the ovens are operating satisfactorily and whether the maximum yield of by-products is being obtained. In some plants experimental ovens are being equipped with separate recovery systems in which by-products from one or more ovens can be treated separately and the yields determined. This arrangement will allow experiments to be made in a more satisfactory manner and should result in making available much valuable information.

DETAILED RESULTS OF TESTS.

Detailed results of coking tests in by-products ovens follow.

Regarding the results for tests 15, 16, 18, 26, 27, 28, 29, 32, 33, and 34, the figures for yields of by-products are from oven tests. These were made at Chattanooga, Tenn., in a small battery of Roberts ovens, the entire battery being operated on the test coal. The data were furnished by Mr. Arthur Roberts, president of the American Coal & By-products Coke Co. No detailed description of the coke from these tests was obtained, but a representative of the company stated that, in his opinion, it was suitable for metallurgical use although it had not been actually tried in a furnace. It is understood that a battery of Roberts ovens which will use Illinois coal for making metallurgical coke is to be built near St. Louis.

TEST 1.

In test 1, about 300 tons of ¼-inch washed coal from Williamson County, district 6, seam 6, was used and the resultant coke was tried as locomotive fuel by the Illinois Central Railroad Co. The result is not known.

The coke looked rough and had poor cell structure, but was comparatively strong and shipped fairly well. The coke was high in ash and suitable for fuel and domestic purposes only. It tended to break in cross fractures and in the shatter test an average of 53.6 per cent stayed on the screen. The shatter test[a] is used to determine the relative breakage during handling. The results given are the percentage remaining on a 2-inch screen.

Tabulated results of the test follows:

Data regarding test 1.

Wet coal charged, pounds	611, 160
Dry coal charged, pounds	531, 458
Wet coke produced, pounds	400, 000
Dry coke produced, pounds	390, 393
Average coking time, hours	23¼

Analysis of dry coal and coke from test 1.

	Coal.	Coke.
Volatile matter, per cent	32. 7	1. 5
Fixed carbon, per cent	56. 3	84. 5
Ash, per cent	11. 0	14. 0
Sulphur, per cent	. 84	. 72
Phosphorus, per cent	. 009	. 011

TEST 2.

In test 2, one car of washed coal from Franklin County, district 6, seam 6, was used. It was pulverized before being charged, so that 70.4 per cent passed through ⅛-inch openings and 94.4 per cent through ¼-inch openings. Three charges were made in a single oven. In one the coal was charged loose in the ordinary manner and in the other two it was compressed before being charged. The coking time was longer, about 46 hours, and the temperature of the ovens lower than usual, being approximately 900° to 950° C.

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[a] For a description of the apparatus and method used in conducting the test, see Belden, A. W., Metallurgical coke: Tech. Paper 50, Bureau of Mines, 1913, p. 38.

The coke from the loose charge was of fairly good size with no indication of sponge. It shattered badly when dropped, breaking into nut size with a large amount of breeze. The cell structure was fairly regular with a rather large percentage of cell space but with thin cell walls. The fusion was complete. The slower coking slightly reduced the formation of fingers but did not add much to the thickness of the cell walls. The coke from the compressed charges was similar to that from the coal charged loose, there being little change in toughness or resistance to crushing. It was not of the highest metallurgical grade. The yields of coke, gas, and tar were not determined. The yield of ammonium sulphate by the laboratory method was 34.7 pounds per ton of coal.

Analysis of coal and coke from test 2.

Constituent.	Loose charge.		Compressed charges.			
	Coal.	Coke.	Coal.	Coke.	Coal.	Coke.
Moisture, per cent	11.11	2.12	18.60	1.72	14.64	1.80
Volatile matter, per cent	37.75	1.45	38.85	1.45	36.84	1.30
Fixed carbon, per cent	54.75	87.75	54.15	87.91	55.44	88.14
Ash, per cent	7.50	10.80	7.00	10.64	7.72	10.56
Sulphur, per cent	1.02	.92	1.09	.98	.98	1.01
Phosphorus, per cent	.008	.009	.010	.014	.005	.013

TEST 3.

In test 3, a car of coal from Franklin County, district 6, seam 6, was used. It was crushed so that 89.6 per cent passed through $\frac{1}{8}$-inch openings and 96.4 per cent through $\frac{1}{2}$-inch openings. Five single-oven charges were made under different conditions.

First, Illinois coal only was charged into a very hot oven and coked in 18 hours. The coke varied in size from very small up to pieces 6 inches across the butt end, with a tendency to break into needlelike pieces. It showed considerable cross fracturing and when dropped it broke into small pieces with a large proportion of breeze. The cell structure was fairly uniform throughout the length of the pieces, the walls were thin, and the cell space was 42.5 per cent. The top of the charge had a tendency to sponge and a few pieces in the charge had a granular structure with no cells. At the center of the charge the coke had a tendency to curl. Because of its friability and weakness it would not be considered a high-grade metallurgical fuel.

Second, Illinois coal only was charged into an oven of moderate heat and coked in 25 hours. The coke appeared much the same as from the first charge except that it tended to form in more blocky pieces.

Third, Illinois coal only was compressed in a stamping machine before being charged into a moderately hot oven, and was coked in

24 hours. The coke appeared much the same as from the uncompressed charge, except that it was heavier and denser with a smaller percentage of cell space. There was little or no improvement in friability and strength of cell walls. Its use would be limited like that of the coke from uncompressed coal.

Fourth, 85 per cent of Illinois coal was mixed with 15 per cent of low-volatile coking coal, charged into a hot oven, and coked in 18 hours. The coke was in pieces of irregular size up to 4 inches across the butt. It showed no tendency to break into fingerlike pieces, but a slight tendency to cross check. When dropped it had an irregular fracture, breaking into small pieces with considerable breeze. It had a poor external appearance with a dead-black surface and a dull ring. The cell structure was rather open and irregular, the walls being fairly thick. A few pieces in the charge had a granular structure. This coke was somewhat stronger and better than from Illinois coal alone.

Fifth, a mixture of 75 per cent of Illinois coal and 25 per cent of low-volatile coal was charged into a hot oven and coked in 18 hours. The coke was in pieces of irregular size up to 8 inches across the butt end. In general appearance it was about the same as that from the 85-15 per cent mixture. It was the best coke of any produced in the test.

The yields of coke, gas, and tar were not determined. The yield of ammonium sulphate by the laboratory method was 29.68 pounds per ton of coal.

Analysis of coal and coke and physical properties of coke, test 3.

Constituent.	Illinois coal only.				Illinois coal only, compressed.		85 per cent Illinois coal and 15 per cent low-volatile coal.		75 per cent Illinois coal and 25 per cent low-volatile coal.	
	Coal.	Coke.	Coal.	Coke.	Coal.	Coke.	Coal.	Coke.	Coal.	Coke.
Moisture, per cent	9.01	1.66	8.00	1.22	17.09	4.00	12.82	1.46	9.01	1.63
Volatile matter, per cent	35.94	.97	36.47	1.11	35.95	1.23	32.98	.85	30.82	1.02
Fixed carbon, per cent	54.91	86.66	55.33	83.79	52.80	83.47	56.66	86.29	59.83	86.34
Ash, per cent	9.15	12.37	8.20	15.10	11.25	15.30	10.36	12.86	9.35	12.64
Sulphur, per cent	1.08	.87	1.08	.89	1.15	.96	1.10	.81	1.01	.91
Phosphorus, per cent.	.006	.007	.006	.007	.006	.008	.007	.009	.005	.006
Apparent specific gravity	....	0.81	....	....	....	0.85	....	....	....	....
Real specific gravity	....	1.47	....	....	....	1.35	....	1.35	....	1.39
Shatter test—per cent retained on 2-inch screen	....	50	....	47	....	45.0	....	69.7	....	73.2

TEST 4.

For test 4, seven cars of coal from Franklin County, district 6, seam 6, were used. The coal was crushed so that 79.5 per cent passed through ⅛-inch openings and 96.1 per cent through ¼-inch openings. Twenty-eight ovens were charged, and the average coking time was 23½ hours.

The general appearance of the coke is shown in Plate III, *A*. A characteristic feature was the tendency to form curved pieces, especially at the bottom of the oven. The coke had a marked tendency to break into fingerlike pieces about 1 inch in diameter. It was remarkably free from cross fractures but was very brittle. When tumbled in a pile it gave a rustling sound. The cell structure was fairly uniform, the cells being small and numerous, and the walls thin. Many pockets were found where the coke did not seem to fuse.

Approximately 290 tons of this coke was used in a copper blast furnace to determine its suitability for such use. The fact was demonstrated that the furnace could be run on this coke.

Data from test 4.

Coal charged, tons	379
Yield of dry coke, including breeze, per cent	76.9
$(NH_4)_2SO_4$ per ton, from laboratory test, pounds	29.36
Shatter test, per cent retained on 2-inch screen	37.2
Apparent specific gravity of coke	0.85
Real specific gravity of coke	1.43
Porosity of coke, per cent	42

Analysis of coal and coke, test 4.

	Coal.	Coke.
Moisture, per cent	8.28	9.05
Volatile matter, per cent	37.09	.87
Fixed carbon, per cent	52.71	84.85
Ash, per cent	10.20	14.28
Sulphur, per cent	1.25	1.02
Phosphorus, per cent	.008	.015

TEST 5.

In test 5, coal from Franklin County, district 6, seam 6, was used. The coal was crushed so that 92.3 per cent passed through ⅛-inch openings. Four ovens were charged, three of them under regular operating conditions. In the fourth the gas was cut down in order that the effect of low heat might be observed. In the first three ovens the average coking time was 18¾ hours, and in the fourth the coke was pushed green in 19½ hours.

In addition, three lots of coal, weighing about 600 pounds each, were specially prepared in boxes before being inserted in the ovens. Box 1 was filled with wet compressed coal, which was pushed in

20 hours after charging; it was rather underdone. Box 2 was filled with dry compressed coal, which was put in an oven at the ordinary temperature, and pushed in 18½ hours. Box 3 was filled with wet uncompressed coal, which was coked at the same temperature and for the same time as the dry coal in box 2.

The coke from the first three ovens was of medium size and showed few cross fractures. It was fingerlike and brittle and showed partly fused material. The cells were small and somewhat irregular. The coke from the fourth oven, in which the charge was coked at low temperature and pushed green, showed a more blocky structure than the others, but it was soft and easily broken. The box tests seemed to indicate that wetting and compressing the coal improved the quality of the coke, making it tougher and more blocky and giving a larger cell structure. Coke from the wet uncompressed coal was blocky and had a large cell structure. The dry compressed coal gave a coke similar to that from the wet compressed coal.

Data from four oven charges, test 5.

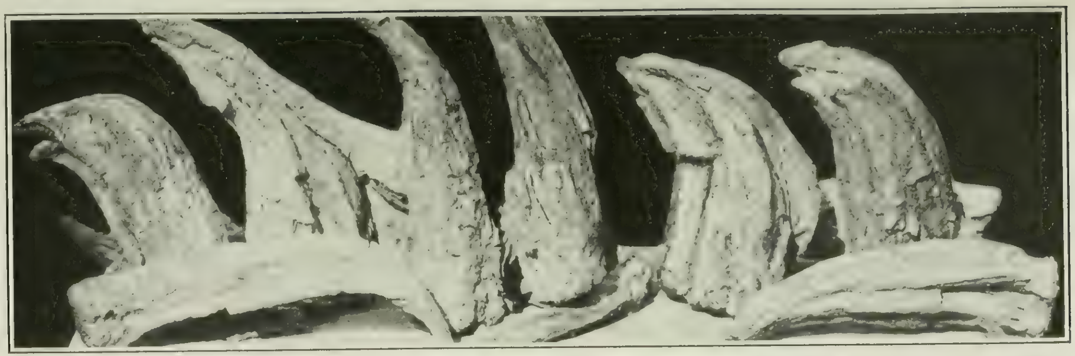
Dry coal charged, pounds	38,996
Dry coke produced, pounds	29,947
Coke, per cent	76.8
Result of shatter test, per cent held on 2-inch screen	51.6
Apparent specific gravity of coke	.78
Real specific gravity of coke	1.62
Porosity, per cent	49.6
$(NH_4)_2SO_4$ per ton, from laboratory test, pounds	27
Tar per ton, gallons	6
Gas per ton, cubic feet	9,700

Analysis of coal and coke, test 5.

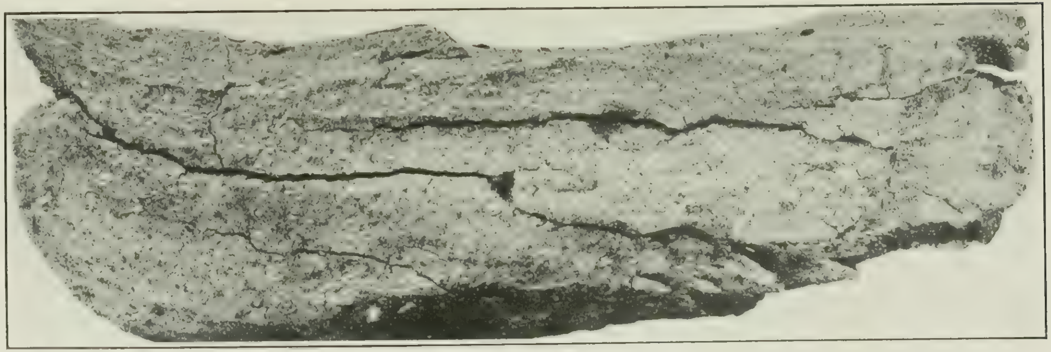
	Coal.	Coke.
Moisture, per cent	8.45	11.40
Volatile matter, per cent	35.21	1.81
Fixed carbon, per cent	54.30	84.25
Ash, per cent	10.49	13.94
Sulphur, per cent	1.10	.82
Phosphorus, per cent	.011	.013

TEST 6.

In test 6, washed slack from Franklin County, district 6, seam 6, was used. The coal was crushed so that 72 per cent passed through ⅛-inch openings and 84 per cent through ¼-inch openings. One oven charge was made of Illinois coal alone, and box tests were made of mixtures of 90 per cent Illinois coal and 10 per cent low-volatile coal, 80 per cent Illinois coal and 20 per cent low-volatile coal, 70 per cent cent Illinois coal and 30 per cent low-volatile coal, and 60 per cent Illinois coal and 40 per cent low-volatile coal. The coking time in each case was 16 hours.



A. COKE FROM 100 PER CENT ILLINOIS (FRANKLIN COUNTY, DISTRICT 6, BED 6) COAL, TEST 4. FEW CROSS FRACTURES; TENDENCY TO FINGER AND FORM CURVED PIECES.



B. COKE FROM 100 PER CENT ILLINOIS (DISTRICT 6, BED 6) COAL, TEST 9. FAIRLY OPEN CELL STRUCTURE; TENDENCY TO BREAK INTO FINGERLIKE PIECES.

The coke from the oven charge was fingerlike and brittle, with few cross checks. The coke from the box tests was more blocky, with irregular cell structure.

Analysis of coals used in test 6.

	Illinois coal.	Low-volatile coal.
Moisture, per cent	0.50	0.30
Volatile matter, per cent	34.03	18.73
Fixed carbon, per cent	55.52	77.31
Ash, per cent	9.95	3.66
Sulphur, per cent	1.22	.76

Analysis of coke, test 6.

Constituent.	Illinois coal only.	90 per cent Illinois coal and 10 per cent low-volatile coal.	80 per cent Illinois coal and 20 per cent low volatile coal.	70 per cent Illinois coal and 30 per cent low volatile coal.	60 per cent Illinois coal and 40 per cent low volatile coal.
Volatile matter, per cent	2.32	2.95	2.93	2.08	1.54
Fixed carbon, per cent	87.50	86.57	88.01	89.98	91.04
Ash, per cent	10.18	10.48	9.06	7.94	7.42
Sulphur, per cent	1.04	0.86	.86	.93	.90

TEST 7.

Coal from Williamson County, district 6, seam 6, was used in test 7. Oven charges were made of mixtures of 70 per cent Illinois coal with 30 per cent low-volatile coal, 60 per cent Illinois coal with 40 per cent low-volatile coal, and 50 per cent Illinois coal with 50 per cent low-volatile coal. The coals were pulverized and mixed before being charged.

The mixtures required a somewhat longer coking time than the regular charges used in the ovens. The coke from the 70–30 mixture was very poor, that from the 60–40 mixture was somewhat better but was slatey and broke considerably on handling. The coke from the 50–50 mixture was better than that from either of the other charges; it was tougher and had less tendency to cross check.

Analysis of coal and coke, test 7.

Constituent.	70 per cent Illinois coal and 30 per cent low-volatile coal.		60 per cent Illinois coal and 40 per cent low-volatile coal.		50 per cent Illinois coal and 50 per cent low-volatile coal.	
	Coal.	Coke.	Coal.	Coke.	Coal.	Coke.
Moisture, per cent	1.00	0.10	2.15	0.04	2.12	0.17
Volatile matter, per cent	25.45	.85	25.99	3.71	28.56	1.36
Fixed carbon, per cent	67.26	87.45	64.85	86.23	61.17	88.29
Ash, per cent	6.29	11.60	7.21	10.02	8.15	10.18
Sulphur, per cent	.98	1.07	.98	.92	1.18	.89

TEST 8.

Coal from district 6, seam 6, was used in test 8. Oven charges were made with Illinois coal only and with a mixture of 20 per cent Illinois coal and 80 per cent low-volatile coal. The yields of by-products when Illinois coal only was used were determined by a laboratory test.

The coke from the charge of Illinois coal alone was in pieces of fair size, with rather open cell structure. It had a porosity of 46.3 per cent, and in a shatter test 71.3 per cent was held on a 2-inch screen. Unfused material was quite noticeable.

Plate IV shows coke from the mixture. The somewhat irregular cell structure, the cross fractures, and the nonfused material are clearly shown. The coke had a porosity of 48.2 per cent, and in a shatter test 80.4 per cent was held on a 2-inch screen.

Yields per ton of 100 per cent Illinois coal as determined in laboratory test 8.

Coke, per cent	69.6
Tar, gallons	7.4
$(NH_4)_2SO_4$ per ton, pounds	33.4
Light oil, pounds	19.6
Gas (including CO_2 and H_2S), cubic feet at 15° C. and 30 inches Hg	10,312

Analysis of coal and coke produced in ovens, test 8.

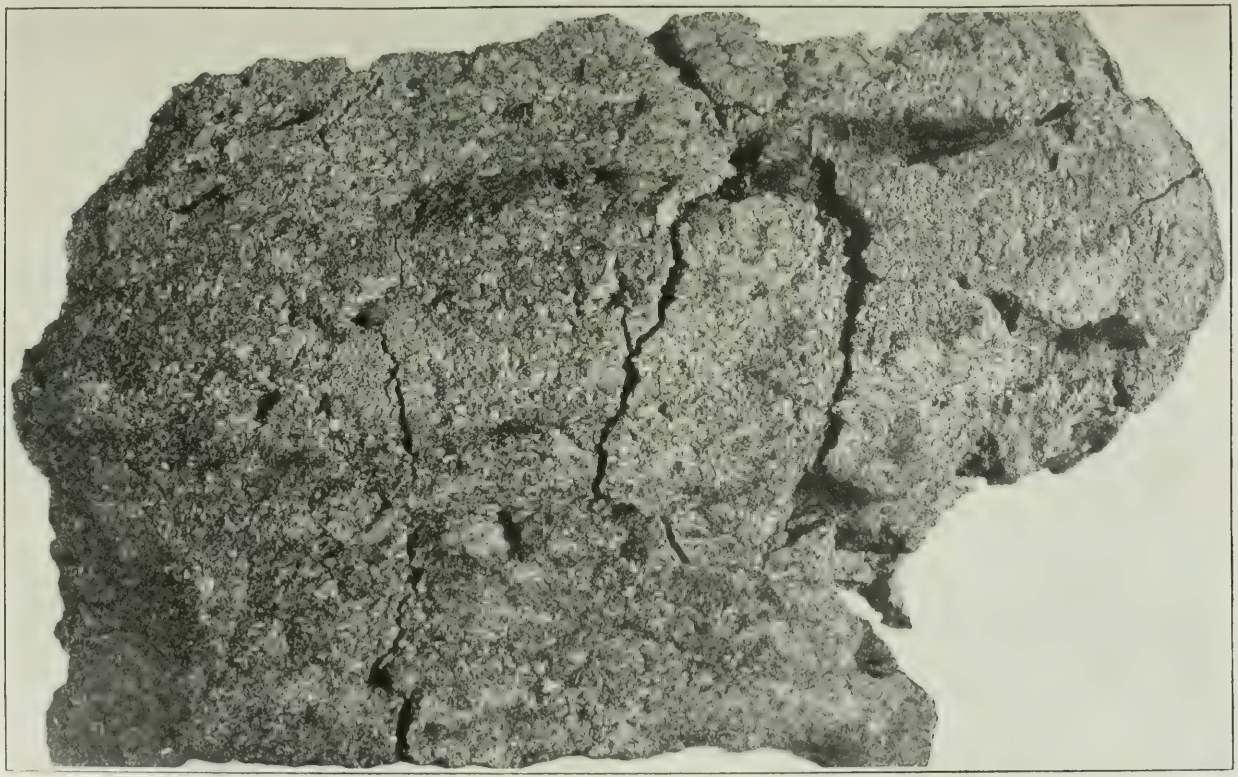
Constituent.	Illinois coal alone.		20 per cent Illinois coal and 80 per cent low-volatile coal.	
	Coal.	Coke.	Coal.	Coke.
Moisture, per cent	2.75	....	3.32	....
Volatile matter, per cent	39.41	3.32	20.04	1.21
Fixed carbon, per cent	51.53	84.16	73.20	90.15
Ash, per cent	9.06	12.52	6.76	8.64
Sulphur, per cent	2.03	1.65	1.02	.97
Phosphorus, per cent	.023	.031	.008	.010

TEST 9.

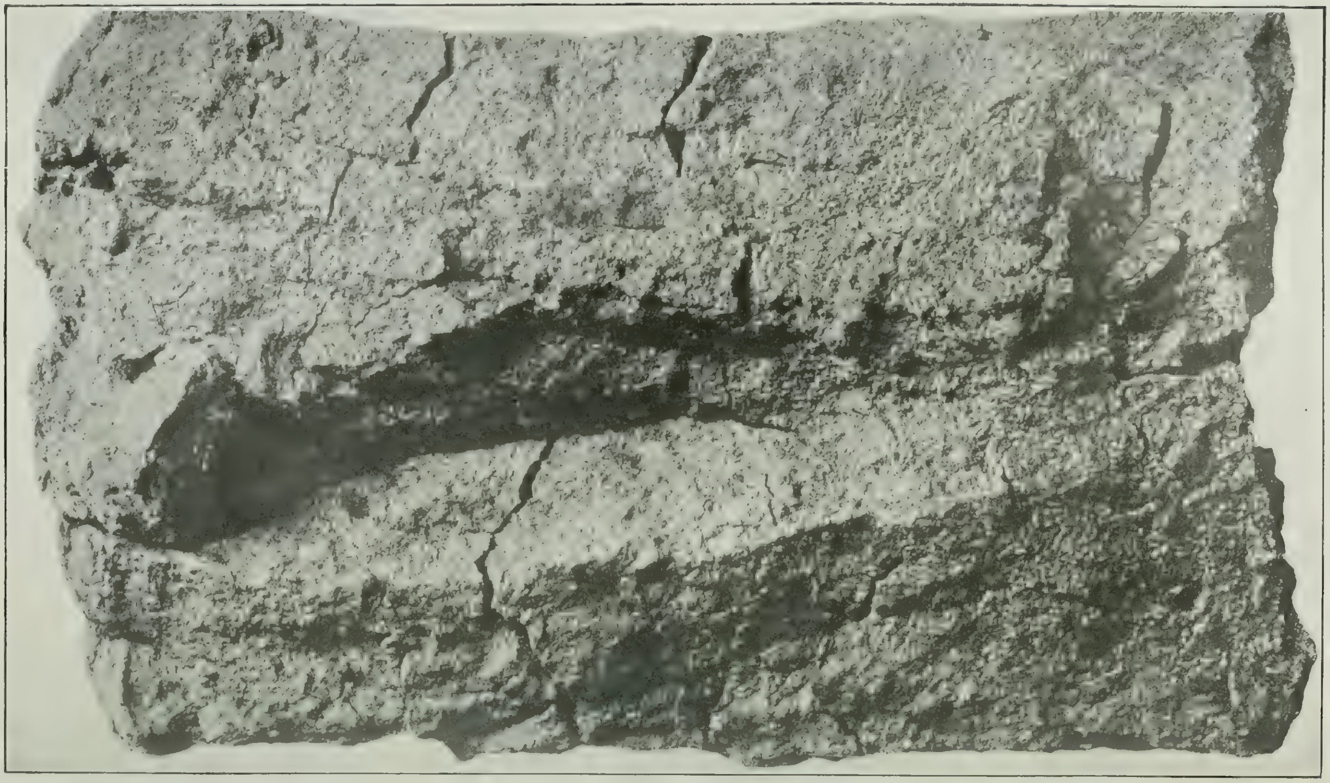
In test 9 coal from district 6, seam 6, was used. Oven charges were made with Illinois coal only and with a mixture of 20 per cent Illinois coal and 80 per cent low-volatile coal. By-products from both charges were determined by a laboratory test.

The coke from Illinois coal alone is shown in Plate III, *B*. The tendency to break up into small fingerlike pieces is noticeable. The cell structure was fairly open and there was some spongy material. The coke had a porosity of 49.9 per cent, and in a shatter test 53.5 per cent was retained on a 2-inch screen.

Coke from the mixture is shown in Plate V. The pieces were of fair size with uniform cell structure. There was some tendency to break in cross fractures, but the coke stood handling well. It had a porosity



COKE FROM 20 PER CENT ILLINOIS (DISTRICT 6, BED 6) COAL AND 80 PER CENT LOW-VOLATILE COAL, TEST 8. SLIGHTLY IRREGULAR CELL STRUCTURE, NONFUSED MATERIAL; TENDENCY TO CROSS FRACTURE.



COKE FROM 20 PER CENT ILLINOIS (DISTRICT 6, BED 6) COAL AND 80 PER CENT LOW-VOLATILE COAL, TEST 9. UNIFORM CELL STRUCTURE, SLIGHT CROSS FRACTURE, FAIR SIZE PIECES.

of 47.5 per cent, and in a shatter test 80.5 per cent was retained on a 2-inch screen.

Yields per ton of coal as determined in laboratory test 9.

	Illinois coal alone.	20 per cent Illinois coal and 80 per cent low-volatile coal.
Coke, per cent	70. 2	81. 3
Tar, gallons	7. 2	4. 0
$(NH_4)_2SO_4$ per ton, pounds	35. 4	20. 8
Light oil, pounds	19. 4	14. 2
Gas (including CO_2 and H_2S), cubic feet at 15° C. and 30 inches Hg	10, 396	10, 088

Analysis of coal and coke produced in ovens, test 9.

Constituent.	Illinois coal alone.		20 per cent Illinois coal and 80 per cent low-volatile coal.	
	Coal.	Coke.	Coal.	Coke.
Moisture, per cent	7. 00	....	4. 40	....
Volatile matter, per cent	38. 83	1. 40	22. 26	1. 21
Fixed carbon, per cent	50. 85	82. 78	69. 10	87. 79
Ash, per cent	10. 32	15. 82	8. 64	11. 00
Sulphur, per cent	1. 59	1. 40	. 83	. 83
Phosphorus, per cent	. 005	. 007	. 006	. 008

TEST 10.

Coal from district 6, seam 6, was used in test 10. Oven charges were made with Illinois coal alone and with a mixture of 20 per cent Illinois coal and 80 per cent low-volatile coal. The by-products from the charge of Illinois coal alone were determined by laboratory test.

Plate VI shows coke from the Illinois coal alone. The tendency to form fingers and to curl are noticeable. The coke was rather soft, had an irregular cell structure, and contained nonfused material. It had a porosity of 50.6 per cent, and in a shatter test 74 per cent was retained on the screen.

Coke from the mixture is shown in Plate I, *B* (p. 16). It was in blocky pieces, the tendency to finger being reduced by the addition of the low-volatile coal. It had a good color and contained little unfused material. The porosity was decreased to 48.4 per cent, and in the shatter test the proportion retained on the screen was raised to 81.5 per cent.

Yields per ton of Illinois coal alone, as determined in laboratory test 10.

Coke, per cent	70. 5
Tar, gallons	6. 0
$(NH_4)_2SO_4$ per ton, pounds	37. 4
Light oil, pounds	19. 8
Gas (including CO_2 and H_2S), cubic feet at 15° C. and 30 inches Hg	10, 663

Analysis of coal and coke produced in ovens, test 10.

Constituent.	100 per cent Illinois coal.		20 per cent Illinois coal and 80 per cent low-volatile coal.	
	Coal.	Coke.	Coal.	Coke.
Moisture, per cent	6.47	....	3.20	....
Volatile matter, per cent	31.47	2.17	20.51	2.03
Fixed carbon, per cent	56.69	82.56	72.31	88.56
Ash, per cent	11.84	15.27	7.18	9.41
Sulphur, per cent	1.00	.84	.70	.72
Phosphorus, per cent	.014	.019	.007	.009

TEST 11.

In test 11, coal from district 5, seam 5, was used. Oven charges were made with Illinois coal only and with a mixture of 20 per cent of Illinois coal and 80 per cent of low-volatile coal. By-products from the Illinois coal alone were determined by laboratory test.

Coke from the Illinois coal alone had a tendency to form fingers and contained some sponge. There was little nonfused material. The porosity was 44.3 per cent, and in the shatter test 74.1 per cent was retained on the screen.

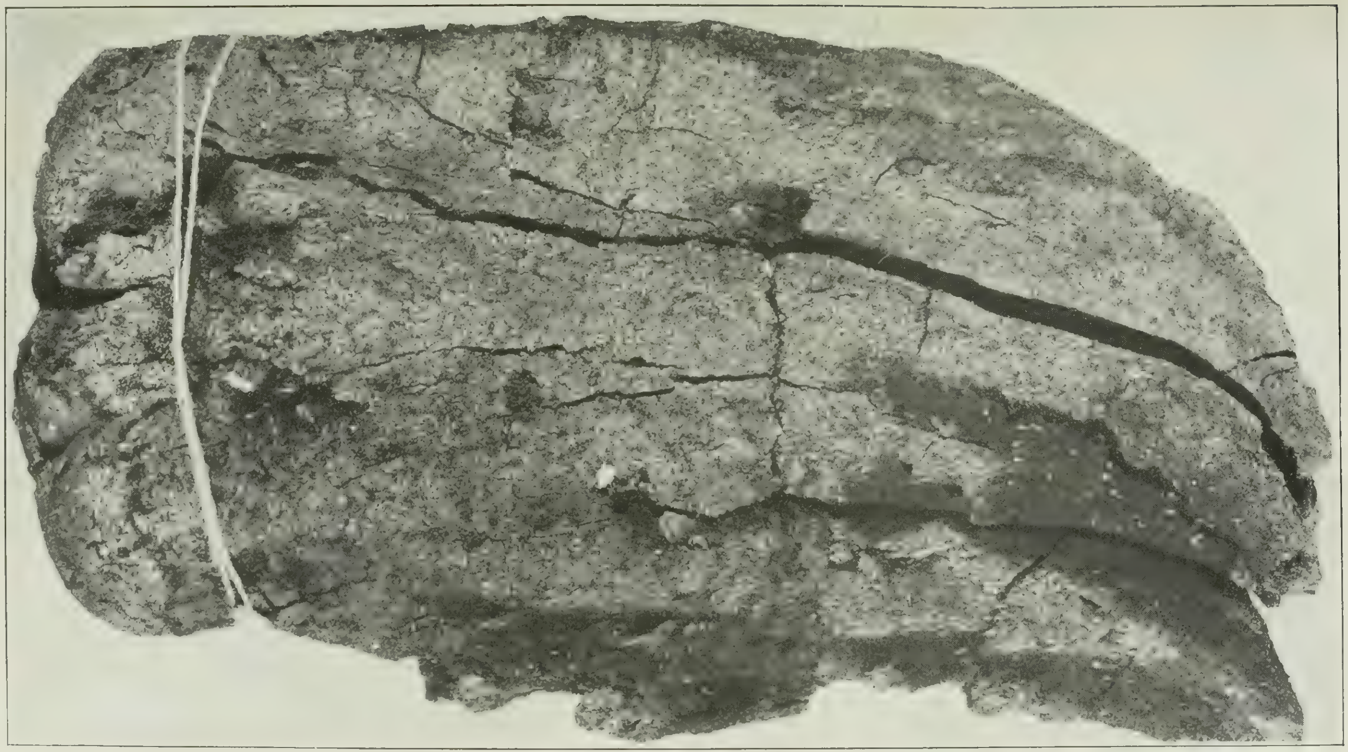
The mixture produced a hard coke with a medium open but uniform cell structure. It was less friable than that from the Illinois coal alone, and in the shatter test 83.9 per cent was retained on the screen. The porosity was 41.6 per cent.

Yields per ton of Illinois coal alone, as determined in laboratory test 11.

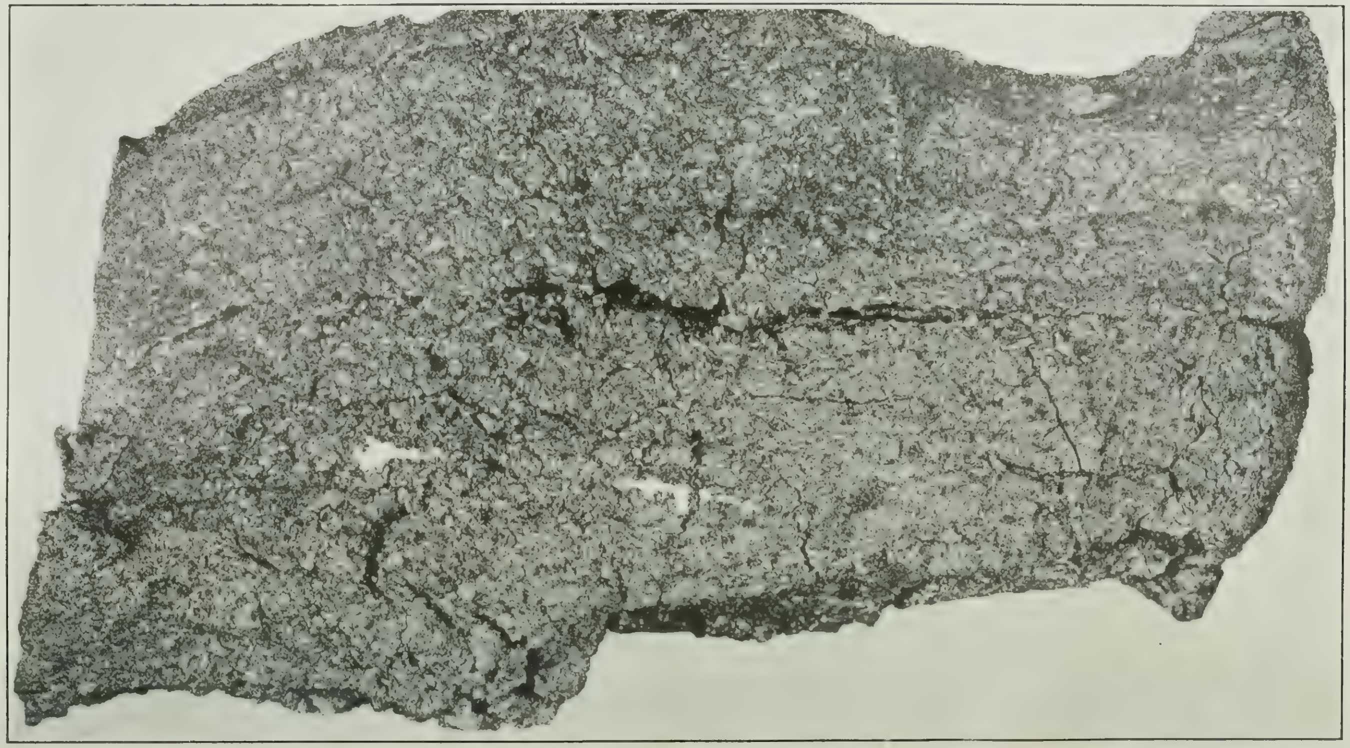
Coke, per cent	73.5
Tar, gallons	4.4
$(NH_4)_2SO_4$ per ton, pounds	34.2
Light oil, pounds	21.6
Gas (including CO_2 and H_2S), cubic feet at 15° C. and 30 inches Hg	10,702

Analysis of coal and coke produced in ovens, test 11.

Constituent.	100 per cent Illinois coal.		20 per cent Illinois coal and 80 per cent low-volatile coal.	
	Coal.	Coke.	Coal.	Coke.
Moisture, per cent	4.20	....	3.13	....
Volatile matter, per cent	33.80	2.97	21.80	2.07
Fixed carbon, per cent	56.36	83.39	71.08	89.11
Ash, per cent	9.84	13.64	7.12	8.82
Sulphur, per cent	2.62	2.36	1.10	.83
Phosphorus, per cent	.011	.009	.010	.009



COKE FROM 100 PER CENT ILLINOIS (DISTRICT 6, BED 6) COAL, TEST 10. TENDENCY TO FINGER, IRREGULAR CELL STRUCTURE, NONFUSED MATERIAL.



COKE FROM 100 PER CENT ILLINOIS (DISTRICT 7, BED 6) COAL, TEST 12. IRREGULAR CELL STRUCTURE, LARGE PROPORTION OF UNFUSED MATERIAL.

TEST 12.

In test 12, coal from district 7, seam 6, was used. Oven tests were made with Illinois coal alone and with a mixture of 20 per cent Illinois coal and 80 per cent low-volatile coal. A laboratory by-product test was made with the Illinois coal alone.

Plate VII shows coke from the test in which Illinois coal was used alone. It was soft and had an irregular cell structure. A large amount of nonfused material was noticeable. The porosity was 51.7 per cent, and in the shatter test 75.1 per cent was retained on the screen.

The general appearance of coke from the mixture is shown in Plate VIII. Fusion was fairly complete but the cell structure was irregular and the coke had a tendency to cross fracture. The porosity was 49.4 per cent, and in the shatter test 81.0 per cent was retained on the screen.

Yields per ton of Illinois coal alone, as determined in laboratory test 12.

Coke, per cent	72. 5
Tar, gallons	6. 2
$(NH_4)_2 SO_4$, per ton, pounds	32
Light oil, pounds	17. 8
Gas (including CO_2 and H_2S), cubic feet at 15°C. and 30 inches Hg.	9, 747

Analysis of coal and coke produced in ovens, test 12.

Constituent.	Illinois coal alone.		20 per cent Illinois coal and 80 per cent low-volatile coal.	
	Coal.	Coke.	Coal.	Coke.
Moisture, per cent	3. 13	....	2. 73	....
Volatile matter, per cent	35. 39	1. 60	20. 25	1. 27
Fixed carbon, per cent	52. 07	82. 44	71. 67	89. 13
Ash, per cent	12. 45	15. 96	8. 08	9. 60
Sulphur, per cent	. 86	. 93	. 70	. 74
Phosphorus, per cent	. 014	. 017	. 008	. 012

TEST 13.

Coal from district 6, seam 6, was used in test 13. Oven tests were made with Illinois coal alone and with a mixture of 20 per cent Illinois coal and 80 per cent low-volatile coal. A laboratory by-product test was made with Illinois coal alone.

Coke from the Illinois coal alone is shown in Plate IX. The cell structure was fairly uniform and there were few cross fractures. The coke was in small pieces and had a tendency to finger. The porosity was 45.4 per cent, and in the shatter test 61.1 per cent was retained on the screen.

Coke from the mixture is shown in Plate X. The fusion was good and the cell structure fairly uniform. The size of pieces was increased, and the friability was lessened by the addition of low-volatile coal. The porosity was raised to 49.8, and in the shatter test the proportion retained on the screen was increased to 80 per cent.

Yields per ton of Illinois coal alone, as determined in laboratory test 13.

Coke, per cent	71. 4
Tar, gallons	6
$(NH_4)_2SO_4$ per ton, pounds	32
Light oil, pounds	24. 5
Gas (including CO_2 and H_2S), cubic feet at 15°C. and 30 inches Hg.	10, 912

Analysis of coal and coke produced in ovens, test 13.

Constituent.	Illinois coal alone.		20 per cent Illinois coal and 80 per cent low-volatile coal.	
	Coal.	Coke.	Coal.	Coke.
Moisture, per cent	2. 90	....	2. 20	....
Volatile matter, per cent	35. 13	2. 05	20. 97	1. 33
Fixed carbon, per cent	54. 29	84. 71	71. 72	89. 75
Ash, per cent	10. 58	13. 24	7. 49	8. 92
Sulphur, per cent	1. 58	1. 32	. 90	. 82
Phosphorus, per cent	.015	.019	.007	.010

TEST 14.

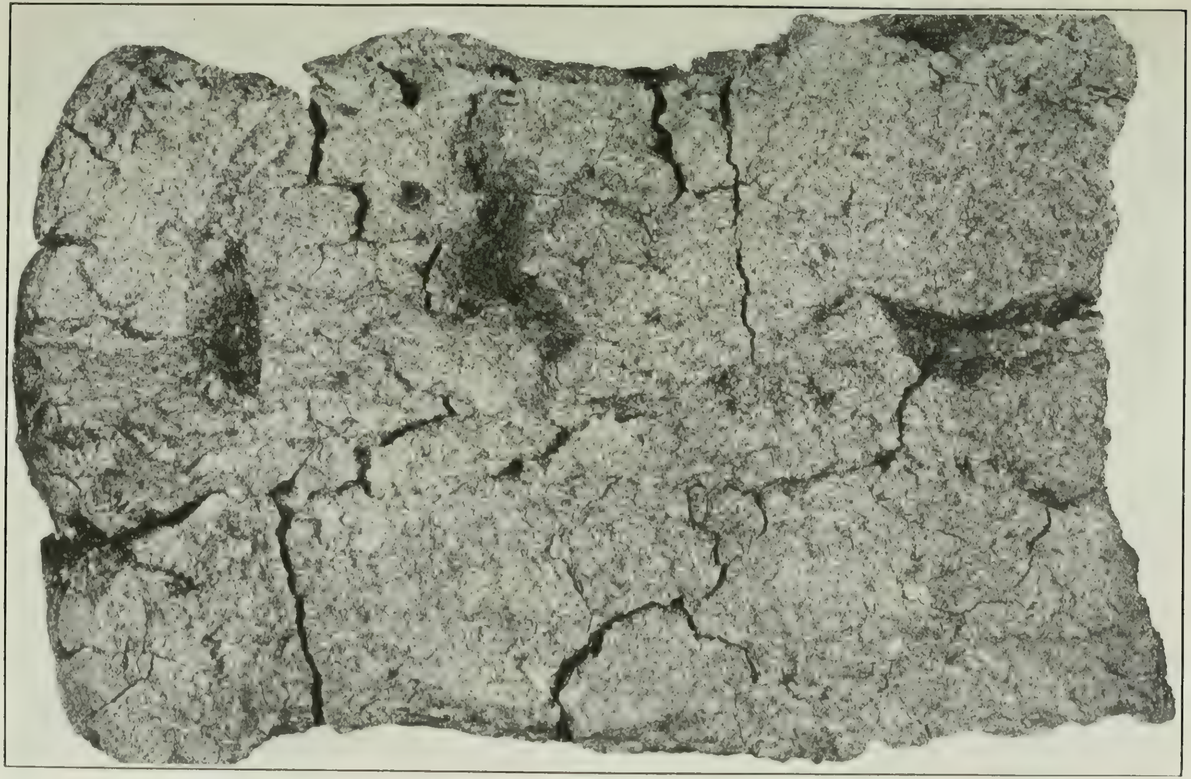
In test 14, coal from district 6, seam 6, was used. Oven charges were made with Illinois coal only and with a mixture of 20 per cent Illinois coal and 80 per cent low-volatile coal. The by-products from both charges were determined in the laboratory.

The general appearance of the coke from the Illinois coal alone is shown in Plate XI. The fusion was fairly good but the cell structure was somewhat irregular. It contained considerable nonfused material. The porosity was 47.6 per cent, and in the shatter test 79.7 per cent was retained on the screen.

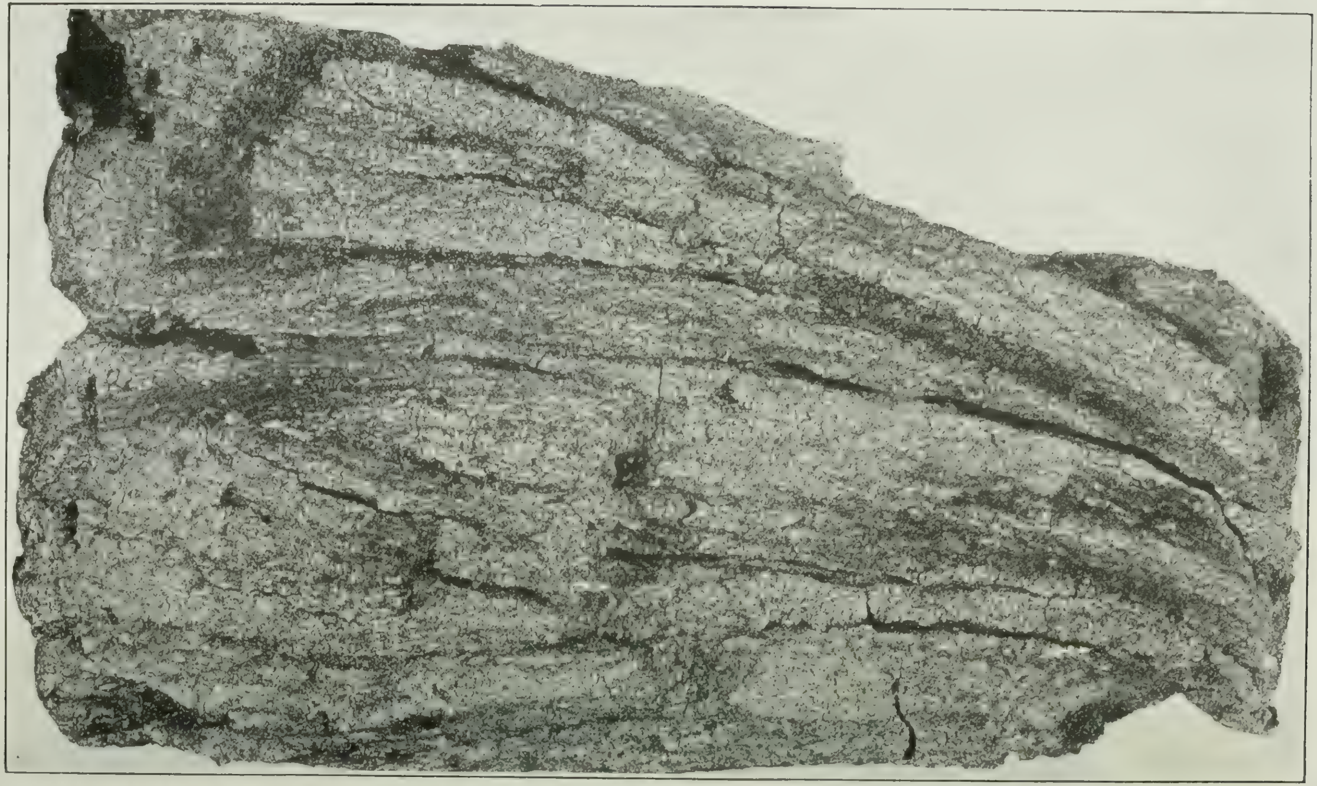
Coke from the mixture was in good-sized pieces and had only a slight tendency to cross fracture. The fusion was good and the coke had a medium cell structure. The porosity was 48.2 per cent, and in the shatter test 89.9 per cent was retained on the screen.

Yields per ton of coal, as determined in laboratory, test 14.

	Illinois coal alone.	20 per cent Illinois coal and 80 per cent low-volatile coal.
Coke, per cent	69. 9	81. 3
Tar, gallons	6. 9	4. 1
$(NH_4)_2 SO_4$ per ton, pounds	32. 9	20. 7
Light oil, pounds	26. 9	14. 8
Gas (including CO_2 and H_2S), cubic feet at 15° C. and 30 inches Hg	10, 561	9, 941



COKE FROM 20 PER CENT ILLINOIS (DISTRICT 7, BED 6) COAL AND 80 PER CENT LOW-VOLATILE COAL, TEST 12. IRREGULAR CELL STRUCTURE.



COKE FROM 100 PER CENT ILLINOIS (DISTRICT 6, BED 6) COAL, TEST 13. FAIRLY UNIFORM CELL STRUCTURE, FEW CROSS FRACTURES, SEEMINGLY GOOD FUSION.

Analysis of coal and coke produced in ovens, test 14.

Constituent.	Illinois coal alone.		20 per cent Illinois coal and 80 per cent low-volatile coal.	
	Coal.	Coke.	Coal.	Coke.
Moisture, per cent	7.00	....	3.10	....
Volatile matter, per cent	37.85	0.92	21.93	1.98
Fixed carbon, per cent	50.80	83.00	68.89	86.41
Ash, per cent	11.34	16.08	9.18	11.61
Sulphur, per cent	2.82	2.36	1.11	1.01
Phosphorus, per cent	.005	.007	.005	.009

TESTS 15 TO 46.

The results of coking tests 15 to 46 are presented in Table 6, following. They are arranged according to districts. Within the district the tests with Illinois coal alone are given first, followed by those with mixtures of Illinois coal and low-volatile coal.

TABLE 6.—*Results of by*

Test No.	Coal tested.	Source of Illinois coal.	Condition of coal.	Quantity of coal used in test.	Number of ovens used in test.	Coking time.	Coke.
1	2	3	4	5	6	7	8
				Cars.		*Hrs.*	*P. ct.*
15	Illinois	Bureau County, district 1, seam 2	Finely crushed	[a] 80	5	13	.....
16	do	Woodford County, district 1, seam 2	do	.....	5	.....	.....
17	do	District 1, seam 7	do	.....	.....	.....	66.8
18	do	Tazewell County, district 4, seam 5	do	[a] 155	10	12	.....
19	do	District 4, seam 5	do	.....	.....	.....	67.6
20	do	Saline County, district 5, seam 5	Washed screenings finely crushed	.....	.....	.....	.....
21	75 per cent Illinois; 25 per cent low-volatile.	do	do	.....	.....	.....	73.1
22	60 per cent Illinois; 40 per cent low-volatile.	do	do	.....	.....	.....	72.37
23[c]	60 per cent Illinois; 40 per cent Pocahontas.	do	Run of mine, finely crushed.	.....	.....	.....	73.44
24	Illinois	Franklin County, district 6, seam 6	Finely crushed	.....	.....	.....	.....
25	do	do	do	1	.....	.....	.....
26	do	do	do	3	.....	12	.....
27	do	do	do	[a] 200	13	12–13	.....
28	do	do	do	[a] 165	11	11½	.....
29	do	do	do	[a] 80	6	12½	.....
30	do	Williamson County, district 6, seam 6	do	1	.....	.....	72.14
31	do	do	do	1	.....	.....	69.17
32	do	do	do	13	12	13	.....
33	do	do	do	[a] 63	.....	18	.....
34	do	do	do	[a] 192	13	15	.....
35	do	District 6, seam 6	.....	.....	.....	.....	67.8
36	do	do	Finely crushed	.....	.....	.....	70.4
37	do	do	do	.....	.....	.....	71.0
38	do	do	do	.....	.....	.....	69.4
39	do	do	do	.....	.....	.....	69.6
40	do	do	do	.....	.....	.....	69.4
41	do	do	do	.....	.....	.....	70.8

[a] Tons.

[b] By-products from oven.

[c] By-product results represent laboratory test; volume of gas given includes CO_2 and H_2S.

product coking tests 15 to 46.

					Analysis of coal and coke from ovens.							Physical properties and appearance of coke.	
Breeze.	Gas per ton of 2,000 pounds.	$(NH_4)_2SO_4$ per ton.	Tar per ton.	Light oil per ton.	Sample.	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Phosphorus.	Shatter test: Per cent held on 2-inch screen.	Remarks.
9	10	11	12	13	14	15	16	17	18	19	20	21	22
P.ct	Cu. ft.	Lbs.	Gal	Lbs		P.ct	P.ct.	P.ct.	P.ct.	P.ct	P.ct.	P.ct	
....	[b]12.700	26.0	12.5	....	Coal.....	5.23	40.77	43.62	10.38	4.15	.....	....	Coke medium hard and dense.
					Coke....	1.20	.21	85.60	12.99	1.89	.....	72.3	
....	[b]12,800	23.0	11.0	....	Coal.....	8.86	39.84	45.37	5.93	2.07	.....	....	Coke hard and dense.
					Coke....	.78	1.03	88.47	9.72	1.06	.....	76.4	
....	[c]10,927	33.0	4.4	19.7	Coal.....	....	39.76	54.39	5.85	2.14	0.003	....	
					Coke....	....	.....	.....	.....	....	.....	....	
....	[b]12,400	27.0	13.0	....	Coal.....	5.69	38.41	46.03	9.87	2.86	.....	....	Do.
					Coke....	.78	1.05	85.62	12.55	1.18	.....	70.0	
....	[c]11,144	32.4	5.4	29.0	Coal.....	....	40.03	46.98	12.99	4.32	.002	....	
					Coke....	....	.....	.....	.....	....	.....	....	
....	....	[d]27.23	....	....	Coal.....	3.98	38.02	50.60	7.40	1.88	.....	....	Coke light in weight, smoky, and black; entirely fused.
					Coke....	.38	1.98	84.74	12.90	1.40	.....	....	
4.3	....	[d]24.23	10.7	....	Coal.....	3.00	33.84	55.66	7.50	1.78	.010	....	Coke porous, with few cross fractures.
					Coke....	.28	1.52	86.20	12.00	1.34	.014	66.0	
3.03	....	.....	....	....	Coal.....	3.71	32.75	55.94	7.60	1.73	.016	....	Coke porous; of poor appearance.
					Coke....	.25	1.49	86.96	11.30	1.16	.017	68.0	
2.61	[d]8,823	22.15	7.04	....	Coal.....	2.01	28.77	58.31	10.91	1.57	.....	....	Coke fairly tough; good looking; not foundry grade.
					Coke....	.35	2.51	81.76	15.38	1.26	.....	75.1	
....	....	.....	....	....	Coal.....	....	37.32	55.50	7.18	2.04	.....	....	Coke porous and fingerlike.
					Coke....	....	.80	87.75	11.45	1.70	.....	44.2	
....	....	.....	....	....	Coal.....	5.07	34.52	49.76	10 65	1.51	.007	....	Coke light, porous, and fragile.
					Coke....	.85	2.51	80.24	16.40	.93	.015	....	
....	[b]12,700	22.0	14.5	....	Coal.....	7.53	32.17	50.46	9.84	1.94	.....	....	Coke hard and dense.
					Coke....	.10	.21	86.12	13.57	1.23	.....	73.0	
....	[b]12,600	26.0	11.0	....	Coal.....	7.48	34.52	50.84	7.16	1.14	.....	....	Do.
					Coke....	.48	.92	88.47	10.13	.81	.....	76.0	
....	[b]12,690	25.0	11.5	....	Coal.....	6.76	35.04	50.43	7.77	1.19	.....	....	Do.
					Coke....	.36	.64	88.92	10.08	.78	.....	75.9	
....	[b]13,000	28.0	12.7	....	Coal.....	5.08	35.78	49.61	9.73	2.66	.....	....	Do.
					Coke....	1.18	.32	86.16	12.34	1.38	.....	68.4	
2.47	[d]9,000	21.11	6.3	....	Coal.....	2.08	27.13	60.67	10.12	1.28	.....	....	Coke coarse and spongy.
					Coke....	....	1.73	82.63	15.64	....	.....	....	
2.48	[d]10,085	21.69	6.9	....	Coal.....	4.16	34.18	50.42	11.24	1.84	.....	....	Coke hard, coarse, and inferior.
					Coke....	.19	1.23	82.61	15.97	1.39	.....	....	
....	[b]11,000	34.0	9.0	....	Coal.....	5.62	35.58	48.89	9.91	1.53	.....	....	Coke hard and dense.
					Coke....	....	.67	86.80	12.53	.97	.....	76.0	
....	[b]13,000	27.0	14.0	....	Coal.....	6.23	41.77	42.62	9.38	3.97	.....	....	Do.
					Coke....	.28	1.07	84.27	14.38	2.16	.....	....	
....	[b]13,000	28.0	11.7	....	Coal.....	5.17	32.33	53.14	9.36	1.43	.....	....	Do.
					Coke....	....	.60	87.10	12.30	.90	.....	73.2	
....	[c]9,466	30.0	12.6	17.1	Coal.....	3.00	38.15	48.49	13.36	4.09	.025	....	
					Coke....	....	.....	.....	.....	....	.....	....	
....	[c]8,989	41.0	9.0	13.3	Coal.....	5.67	32.89	53.77	13.34	1.45	.049	....	Coke small in size, light in weight; had open cell structure.
					Coke....	....	2.10	80.28	17.62	1.40	.054	78.6	
....	[c]10,777	35.2	5.5	27.7	Coal.....	....	35.39	56.00	8.61	1.17	.007	....	
					Coke....	....	.....	.....	.....	....	.....	....	
....	[c]9,768	37.8	9.4	13.5	Coal.....	3.33	35.00	56.80	8.20	2.02	.025	....	Coke soft; fingerlike; open cell structure.
					Coke....	....	2.18	84.46	13.36	1.38	.045	82.6	
....	[c]9,724	38.0	8.4	19.2	Coal.....	2.00	39.07	49.23	11.70	1.17	.004	....	Coke had poor irregular cell structure; considerable nonfused material.
					Coke....	....	2.76	81.46	15.78	1.05	.005	76.3	
....	[e]9,434	35.8	10.4	11.4	Coal.....	3.00	31.84	52.32	15.84	3.25	.027	....	Coke fingerlike and brittle; showed spongy material.
					Coke....	....	1.95	80.20	17.85	2.05	.033	72.2	
....	[c]10,129	35.4	6.8	12.8	Coal.....	2.33	35.58	52.86	11.56	2.18	.023	....	Coke fair size; rough surfaces; considerable nonfused material.
					Coke....	....	1.90	84.70	13.40	2.07	.030	80.4	

[d] By-products determined by laboratory test.
[e] Results represent averages from two trials.

TABLE 6.—*Results of by-product*

Test No.	Coal tested.	Source of Illinois coal.	Condition of coal.	Quantity of coal used in test.	Number of ovens used in test.	Coking time.	Coke.
1	2	3	4	5	6	7	8
				Cars.		*Hrs.*	*P.ct.*
42	85 per cent Illinois; 15 per cent Durham.	Franklin County, district 6, seam 6	(*a*)	......	....	......	.....
43	20 per cent Illinois; 80 per cent low-volatile.	....do	......	......	....	......	81.66
44	.....do	District 6, seam 6	Finely crushed	......	....	......	81.4
45	Illinois	District 8, seam 6	.....do	......	....	......	68.9
46	20 per cent Illinois; 80 per cent low-volatile.	District 8, seam 6	.....do	......	....	......	.....

[a] 74.6 per cent passed through ⅛-inch screen.

coking tests 15 to 46—Continued.

Breeze.	Gas per ton of 2,000 pounds.	$(NH_4)_2SO_4$ per ton.	Tar per ton.	Light oil per ton.	Analysis of coal and coke from ovens.							Physical properties and appearance of coke.	
					Sample.	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Phosphorus.	Shatter test: Per cent held on 2-inch screen.	Remarks.
9	10	11	12	13	14	15	16	17	18	19	20	21	22
P.ct	*Cu. ft.*	*Lbs.*	*Gal*	*Lbs*		*P.ct*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct*	*P.ct.*	*P.ct*	
....	....	....	....	....	Coal.....	8.80	34.67	57.42	7.91	1.33	......	....	Coke hard and dense; slight tendency to form fingers.
					Coke....	5.04	2.52	84.69	12.79	1.09	......	....	
....	[b]10,562	20.61	....	....	Coal.....	.76	20.78	69.01	9.45	1.06	......	....	
					Coke....	....	.....	.....	.....	....	......	....	
....	[c]10,195	20.2	3.7	15.9	Coal.....	4.80	21.09	70.79	8.12	.80	.005	....	Vertically cross fractured; cell structure rather irregular; fusion complete.
					Coke....	....	1.29	87.02	11.15	.76	.007	76.2	
....	[c]10,782	37.0	2.6	12.8	Coal.....	2.20	41.47	42.71	11.32	2.76	.009	....	Coke easily reduced to powder; had no cell structure.
					Coke....	....	5.22	79.21	15.57	2.57	.013	77.2	
....	....	....	....	....	Coal.....	....	21.86	69.62	8.52	1.03	.007	....	Coke irregular and cross fractured; poor cell structure; nonfused material.
					Coke....	....	3.00	85.75	11.25	.61	.006	82.8	

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[b] By-products determined by laboratory test; volume of gas given includes CO_2 and H_2S; composition of gas was as follows, values representing percentages: CO_2, 1.6; illuminants, 1.9; O_2, 0.4; CO, 4.7; CH_4 25.0; H_2, 61.5; N_2, 4.9.

[c] By-product results represent laboratory test; volume of gas given includes CO_2H_2S.

TESTS OF ILLINOIS COALS IN GAS RETORTS.

Although Illinois coals have been used for making gas for several years, their use has been confined to some of the smaller plants and has not grown rapidly. In order to determine the suitability of the Illinois coals for gas manufacture, tests have been made from time to time, and the results of some of the tests are given in the following pages.

At present, plants using Illinois coal only are situated at Centralia, Mount Vernon, and Duquoin, Ill., and at St. Charles, Booneville, Cape Girardeau, and Clinton, Mo. Plants using part Illinois coal and part Eastern gas coal are given on page 63.

TESTS AT ST. LOUIS, MO.

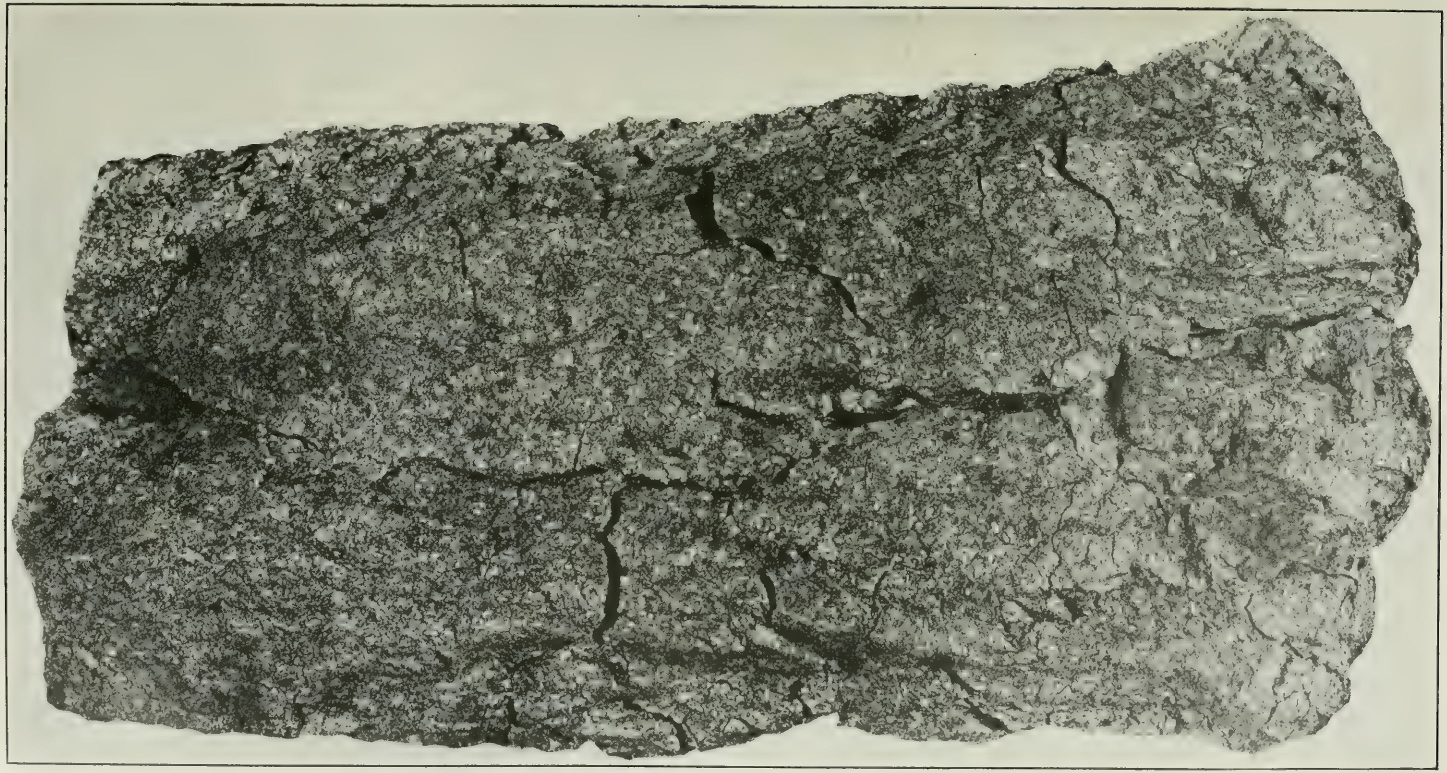
Tests on a large scale under actual operating conditions made by a gas company at St. Louis showed the yields that can be expected from Illinois coals in commercial practice. The duration of the tests was sufficient to show any difficulties in operation due to the nature of the coal and to give average results. The products were systematically sampled and carefully analyzed during the tests, and all the figures given are average results obtained from several samples.

TEST 1.

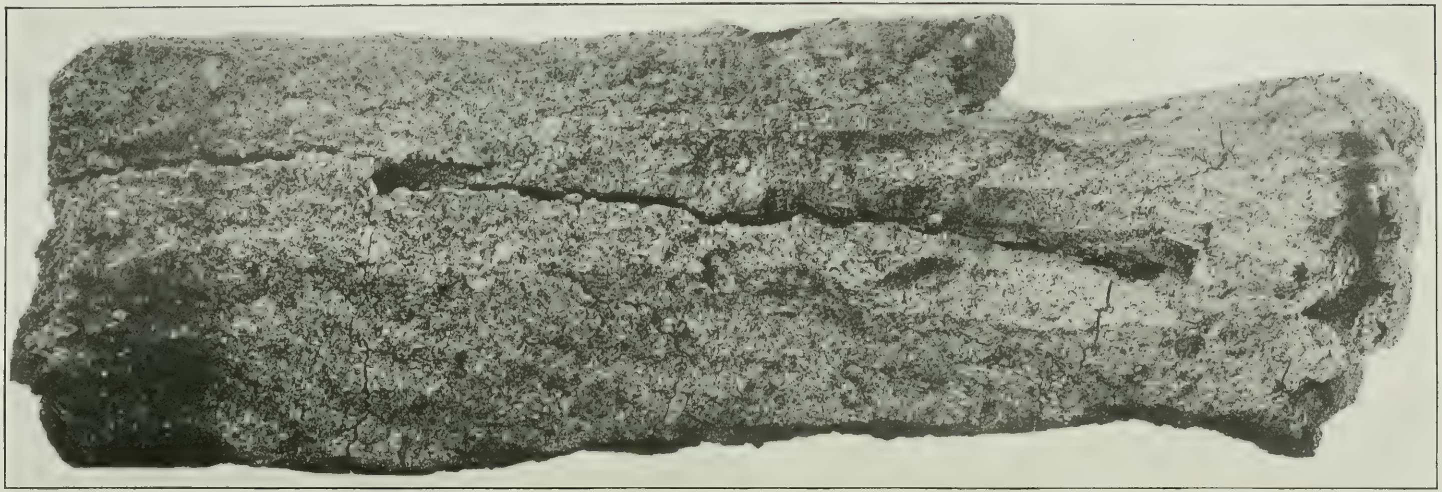
Test 1 was a six-day test of coal from Perry County, district 6, seam 6. The coal was of lump and egg size. The lump contained more slate and iron pyrites than the egg, which appeared to be comparatively clean. The coal as mined contained a white substance, probably calcium carbonate or calcium sulphate, as a thin parting.

The coal was carbonized in a retort house of 32 benches of fours, direct fired. During the first three days about one half of the total number of active retorts were charged with 500 pounds each and the other half were charged with 525 pounds each. The last three days the charges were 525 and 550 pounds to the retort. The period of carbonization was 4¾ hours. Several charges of 500 pounds each were carbonized for 6, 8, and 12 hours, and 1 charge of 1,000 pounds was carbonized for 12 hours in order to show the effect on the coke. No trouble was experienced in the retort house while this coal was being carbonized.

The average yield of gas, corrected to 60° F. and 29.5 inches of Hg was 3.92 cubic feet per pound of coal. The crude gas contained 474 grains of hydrogen sulphide per 100 cubic feet at the outlet of the exhauster and 369 grains at the outlet of the scrubbers. The average organic sulphur was 11.6 grains. The quality of the gas was good but the yield was low. The daily (24-hour) production of gas, and its quality, were as follows:



COKE FROM 20 PER CENT ILLINOIS (DISTRICT 6, BED 6) COAL AND 80 PER CENT LOW-VOLATILE COAL, TEST 13, UNIFORM CELL STRUCTURE, GOOD FUSION.



COKE FROM 100 PER CENT ILLINOIS (DISTRICT 6, BED 6) COAL, TEST 14. GOOD FUSION, SLIGHTLY IRREGULAR CELL STRUCTURE.

Data regarding daily production of gas in test 1.

Item.	First day.	Second day.	Third day.	Fourth day.	Fifth day.	Sixth day.
Quantity of gas made, corrected to 60° F. and 29.5 inches Hg, thousand cubic feet	1,202	1,242	1,195	1,207	1,229	1,164
Coal carbonized, pounds	302,500	306,000	307,200	313,500	314,400	302,200
Average yield of gas per pound of coal, cubic feet	3.97	4.05	3.89	3.85	3.91	3.85
Candle power of 24-hour sample	14.7	14.6	13.5	12.0	14.7	12.9
Gross heating value of 24-hour sample, B. t. u	617	604	600	592	617	601

Several carefully weighed charges were carbonized for 4¾ hours and the coke weighed hot to determine the yield. An average of 56 per cent was obtained. The coke was light and porous and contained considerable unfused material. It was of poor grade. The percentage of breeze was high. The coke was tried for the production of water gas in two 11-foot generators. Its action was not as satisfactory as that of Pittsburgh coke, the yield for the six days being about 10 per cent less than the usual yield with the Pittsburgh coke. The difference was due to the greater amount of clinkers and the increased time required for removing them. The daily record of the water gas test follows:

Data regarding production of water gas from coke produced in test 1.

Item.	First day.	Second day.	Third day.	Fourth day.	Fifth day.	Sixth day.
Quantity of gas made, corrected to 60° F. and 29.5 Hg, thousand cubic feet	4,351	4,296	4,045	4,260	5,586	5,706
Time on clinkers and breakups, hours and minutes	4 49	5 15	6 8	5 10	8 6	7 56
Coke per thousand cubic feet of gas made, pounds	36.5	35.8	37.1	38.4	37.3	37.6

No determination was made of the quantity of tar produced, but samples taken at the overflow of the hydraulic main were examined for appearance and specific gravity of the tar and for the free carbon contained in it. It was thin and had a tendency to run through connections; the specific gravity was 1.17 and the free carbon was 10 per cent. The average yield of ammonia (NH_3) was 5.21 pounds per ton of coal. The strength of liquor in the various storage wells was not determined.

Summary of results of test 1.

Weight of coal carbonized, tons	922.9
Duration of test, days	6
Gas per pound of coal, cubic feet	3.92
Coke, per cent	58
Ammonia per ton of coal, pounds	5.21
Coke per 1,000 feet of water gas, pounds	37.1
Candlepower of gas	13.7
Heating value of gas, B. t. u	605

Average composition of gas by volume, test 1.

Constituent.	Per cent.
CO_2	2.9
Illuminants	4.2
O_2	1.4
CO	8.9
CH_4	29.4
H_2	42.1
N_2	11.1

Average analysis of coal and coke, test 1.

	Coal.	Coke.
Moisture, per cent	6.53	......
Volatile matter, per cent	36.42	5.64
Fixed carbon, per cent	47.48	79.07
Ash, per cent	9.57	15.29
Sulphur, per cent	1.00	.76
Heating value, B. t. u	12,148	12,367

TEST 2.

In test 2 "egg" coal from Franklin County, district 6, seam 6, was used.

The coal was carbonized in four benches of fours of the direct-fired type. At the start 525-pound charges and 4¾-hour periods were used. These were first changed to 600 pounds and 6 hours, then to 700 pounds and 7 hours, and later to 800 pounds and 8 hours. With the first three combinations the coal was well carbonized; with the last combination a considerable amount of gas remained in the coke at the end of the period. Subsequently charges of 700 pounds and an 8-hour period were used. Because the supply of coal was small for a test with all of the retorts, the yield of gas was determined by a laboratory method. For this purpose a carefully selected sample of coal was taken from each car as it was unloaded. Analyses of these samples were made and the composition and the yield of gas were determined in a laboratory retort. Five cubic-foot samples of gas were also taken from the hydraulic main, near the center of the four benches, in order to determine the composition of the foul gas from the retorts. The composition of this gas and that obtained in the laboratory retort are given in the summary of results of this test.

The coke obtained with the first four combinations of charge and coking period was soft and porous, there being no noticeable difference caused by changes in weight of charge and time of carbonization.

The coke from the 700-pound charge and 8-hour period seemed slightly harder and denser than that from the other combinations. The coke was tested in a water-gas generator, and made a hard clinker, owing to fusion of the excessive amount of ash. The time of clinkering was increased from 25 to 30 minutes per watch. The steam pressure was increased 2 pounds above that ordinarily used with Pittsburgh coke, in order to soften the clinker, but the increase of steam pressure lowered the heat in the generator and materially decreased the gas production. More Illinois coke was required than Pittsburgh during an equal period of time.

Summary of results of test 2.

	Results from working bench.	Results from laboratory retort.
Coke, including breeze, per cent	57.1	61.3
Gas per pound of coal, cubic feet		5.32
Candlepower of gas		17.3
Heating value per cubic foot of gas, B. t. u	661	632
H_2S per 100 cubic feet of gas, grains	1,235	....
Organic sulphur per 100 cubic feet of gas, grains	26	....

Average composition of gas, test 2.

	Results from working bench.	Results from laboratory retort.
CO, per cent	2.2	3.4
Illuminants, per cent	3.8	5.4
O_2, per cent	.5	.7
CO, per cent	8.5	10.4
CH_4, per cent	34.8	30.3
H_2, per cent	46.2	43.3
N_2, per cent	3.0	6.3

Average analysis of coal and coke, test 2.

	Coal.	Coke.
Moisture, per cent	3.55	1.12
Volatile matter, per cent	37.55	4.82
Fixed carbon, per cent	48.63	76.55
Ash, per cent	10.42	17.51
Sulphur, per cent	2.32	2.46
Heating value, B. t. u	12,392	11,502

TEST 3.

Test 3 was a 15-day test of coal from Perry County, district 6, seam 6. The coal contained considerable "slate," much of it being in thin flat chunks.

The test was made with four benches of fours of the direct-fired type. The charges were 500 pounds each, and the time of carbonization was 4¾ hours during the first part of the test and 6 hours during the later part. Two retorts were charged with 1,000 pounds each, a 14-hour period of carbonization being used. Gas analyses were made daily. The tar and ammonia wells were measured before and after the test and before and after each time either tar or ammonia was pumped away. Samples of ammonia liquor were taken at the same time.

The yield of gas, corrected to 60° F. and 29.5 inches of Hg., was 4.136 cubic feet per pound of coal. The low yield can be accounted for to some extent by the high ash content of the coal. The quality of the gas was good, comparing well with that from Pittsburgh coal.

The coke from two retorts of the same bench was weighed hot. The average yield, including breeze, was 60.2 per cent, which is 7 or 8 per cent less than the yield from Pittsburgh coal. The coke was light and friable and contained a number of unfused places which seemed to prevent the formation of large pieces. It was tested as fuel under the benches, where it furnished satisfactory heat and did not form a hard clinker. The ash content was high.

The ammonia was 6.42 pounds per ton of coal carbonized, being somewhat higher than from Pittsburgh coal. The tar averaged 10.65 gallons per ton of coal, which is considerably less than is obtained from Pittsburgh coal.

Summary of results of test 3.

Weight of coal carbonized, tons	226.7
Duration of test, days	12
Gas per pound of coal, cubic feet	4.136
Coke, per cent	54.4
Breeze, per cent	5.8
Ammonia per ton of coal, pounds	6.42
Tar per ton of coal, gallons	10.65
Coke fired per ton of coal carbonized, pounds	251
Candlepower of gas	15.6
Heating value per cubic foot, B. t. u	656
H_2S per 100 cubic feet, grains	585

Average composition of gas, test 3.

Constituent.	Per cent.
CO_2	1.9
Illuminants	4.4
O_2	.5
CO	8.0
CH_4	40.0
O_2	40.1
N_2	5.1

Average analysis of coal and coke, test 3.

Constituent.	Coal.	$4\frac{3}{4}$-hour coke.	6-hour coke.	14-hour coke.
Moisture, per cent	4.36	....	....	....
Volatile matter, per cent	34.18	6.17	4.97	4.50
Fixed carbon, per cent	48.69	80.23	79.24	81.19
Ash, per cent	12.77	13.60	15.79	14.31
Sulphur, per cent	1.17	.92	.77	.98
Heating value, B. t. u	11,808	11,939	11,451	11,274

TEST 4.

Test 4 was a 24-hour run with 6-inch coal from Franklin County, district 6, seam 6.

The coal was carbonized in a retort house of 32 benches of fours, direct fired. Charges of 450 and 500 pounds to the retort were made during the day and charges of 400 and 450 pounds during the night because the supply of coal was not sufficient to make the larger charges for 24 hours. The time of carbonization was 4¾ hours. Three charges of 500 pounds each were carbonized for 6, 8, and 12 hours, and one charge of 1,000 pounds for 12 hours for the purpose of observing the resultant coke.

The average yield of gas, corrected to 60° F. and 29.5 inches of Hg., was 4.06 cubic feet per pound of coal. The crude gas contained 604 grains of hydrogen sulphide per 100 cubic feet at the outlet of the exhauster and 505 grains at the outlet of the scrubbers. The quality was good, but the yield was low compared with the values for Eastern gas coals.

The yield of coke, including breeze, was 60 per cent. The quality was poor, being similar to that from the other tests. With the first three combinations of charge and coking time no difference could be observed on account of the longer periods of carbonization. The coke from the 12-hour charge appeared to be somewhat improved, but unfused pieces were noticeable. The coke was tried in water-gas generators, with results similar to those obtained with the coke from other samples of Illinois coal. A longer time was required to remove clinkers and a larger quantity of fuel was used per 1,000 feet of gas than with Pittsburgh coke.

Summary of results of test 4.

Weight of coal carbonized, tons	140. 9
Duration of test, hours	24
Gas per pound of coal, cubic feet	4. 06
Coke, including breeze, per cent	60
Ammonia at outlet of exhauster, pounds	4. 18
Coke per 1,000 feet of water gas, pounds	36. 5
Candlepower of gas	16. 7
Heating value of gas, B. t. u	644

Average composition of gas, test 4.

Constituent.	Per cent.
CO_2	2. 4
Illuminants	3. 6
O_2	0. 5
CO	9. 0
CH_4	32. 9
H_2	44. 1
N_2	7. 5

Average analysis of coal and coke, test 4.

	Coal.	Coke.
Moisture, per cent	4.57	
Volatile matter, per cent	36.35	4.78
Fixed carbon, per cent	49.25	83.44
Ash, per cent	9.83	11.78
Sulphur, per cent	1.37	0.73
Heating value, B. t. u	12,621	12,698

TEST AT ANN ARBOR, MICH.

In illuminating-gas investigations commenced by the technologic branch of the United States Geological Survey in 1908 effort was made to ascertain the possibility of using for gas making other and cheaper fuels than Eastern coals. The work was carried on at Ann Arbor, Mich., at the experimental plant of the Michigan Gas Association. Alfred H. White, professor of chemical engineering at the University of Michigan, directed the work and was in charge of the investigations. The fuel-testing work was subsequently transferred to the Bureau of Mines and the report of the tests was published by that bureau.[a]

Among the coals tested was a sample of ¾-inch size from the No. 4 mine at Harrisburg, Saline County, Ill., district 5, seam 5.

The test was made in a single retort of the standard ⌓ shape, which was one of the upper retorts of a bench of six with three-quarter depth regenerative setting. This retort was equipped with a complete system for cleaning the gas and measuring and sampling the products independently of the other five. A charge of 400 pounds was carbonized for about 4½ hours. The coke produced was dark and easily broken. The yield of gas was 4.3 cubic feet per pound of coal, with an average candlepower of 15.2. The heating value of the gas was 632 B. t. u. per cubic foot and 2,718 B. t. u. per pound of coal. The ammonia yield was large, being 6.38 pounds per ton of coal, or 19 per cent of the theoretical. The amount of naphthalene was extremely small, probably because of the low retort temperature. The hydrogen sulphide in the gas at the outlet of the scrubber was 50 per cent more than in gas from Pittsburgh coal.

The results in the summary following are on the basis of coal as charged to the retort.

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[a] See White, A. H., and Barker, Perry, Coals available for the manufacture of illuminating gas: Bull. 6, Bureau of Mines, 1911, 77 pp.

Summary of results of coking test of Harrisburg coal at Ann Arbor, Mich.

Weight of coal carbonized, pounds	400
Gas, per cent	14.3
Coke, per cent	62.3
Tar, per cent	8.6
Ammonia liquor, per cent	6.0
Unaccounted for, per cent	8.8
Gas per pound of coal, cubic feet	4.3
Candlepower	15.2
Gross heating value per cubic foot, B. t. u	632
Ammonia per ton of coal, pounds	6.38
Tar per ton of coal, pounds	166
Naphthalene per ton of coal, pounds	4.5
Hydrogen sulphide at outlet of scrubbers per 100 cubic feet of gas, grains	1,390
Maximum temperature in retort, ° F	1,360
Average temperature, exterior of retort, ° F	1,779

Average composition of gas from Ann Arbor test.

Constituent.	Per cent.
CO_2	2.5
Illuminants	3.7
O_2	.8
CO	7.9
CH_4	33.5
H_2	45.6
N_2	6.0

Average analysis of coal and coke, Ann Arbor test.

	Coal as charged.	Dry coke.
Moisture, per cent	4.66	......
Volatile matter, per cent	34.44	2.22
Fixed carbon, per cent	53.71	85.48
Ash, per cent	7.19	12.30
Sulphur, per cent	1.96	2.08
Heating value, B. t. u	12,919	12,427

TEST AT DE KALB, ILL.

A test of coal from Perry County, district 6, seam 6, made at De Kalb, Ill., gave the following results:

Weight of coal, pounds	20,600
Gas, obtained, cubic feet	93,400
Yield of gas per pound of coal, cubic feet	4.53
Coke, including breeze, pounds	13,800
Coke, per cent	56
Breeze, per cent	11

Composition of gas.

CO_2, per cent	2.4
Illuminants, per cent	3.5
O_2, per cent	1.1
CO, per cent	10.6
CH_4, per cent	30.8
H_2, per cent	43.9
N_2, per cent	8.2
Heating value, B. t. u	554

Analysis of coal and coke.

	Coal.	Coke.
Moisture, per cent	9.0	0.5
Volatile matter, per cent	36.0	1.0
Fixed carbon, per cent	46.0	85.5
Ash, per cent	9.0	13.0
Sulphur, per cent	.85	1.04

USE OF ILLINOIS COAL WITH EASTERN GAS COAL.

During the past two years the practice of using one-third Illinois coal and two-thirds Eastern gas coal has been adopted at some gas plants. The customary method of operating with two coals is to charge one-third of the retorts in a bench with Illinois coal and the other two-thirds with Eastern gas coal. In this way the coke from Illinois coal can be kept separate from that from the Eastern gas coal and can be used for heating the retorts and for the production of water gas, and the coke from Eastern gas coal can be sold for domestic use. In a few cases the coals have been mixed before being charged into the retorts.

The saving resulting from this practice varies with the comparative cost of the coals which depends largely on freight rates. With Eastern gas coal costing $1 a ton more than Illinois coal, the use of one-third Illinois coal represents a saving of about 2 cents per 1,000 feet of gas. Following are given comparative data for a plant making about 200,000 feet of gas daily, showing results when Eastern gas coal is used alone and when it is used in combination with one-third Illinois coal.

The figures give the cost of fuel and labor per 1,000 cubic feet of gas and do not include fixed charges.

General cost data for fuel and labor in a gas plant making about 200,000 cubic feet of gas daily.

Cost When Eastern Gas Coal was Used.

1,374,600 pounds of coal at $3.20 per ton, used in 31 days	$2,199.36
220,336 pounds of coke at $4 per ton	440.67
Labor	650.71
	3,290.74

COST WHEN ONE-THIRD ILLINOIS COAL AND TWO-THIRDS EASTERN GAS COAL WERE USED.

2,352,779 pounds of Eastern coal at $3.20 per ton, used in 80 days	$3,764.45
822,620 pounds of Illinois coal at $2.22 per ton	913.11
528,741 pounds of coke at $4 per ton	1,057.48
Labor	1,310.76
	7,045.80

Detailed cost data.

Coal used.	Yield of gas, 1,000 cubic feet.	Yield per pound.	Heating value.	Average cost.				Average credit coke and tar.	Average net cost per 1,000 cubic feet.
				Coal.	Bench fuel.	Labor.	Total.		
		Cu. ft.	*B.t.u.*						
Eastern	6,737	4.90	587	$0.326	$0.065	$0.096	$0.487	$0.269	$0.218
Eastern and Illinois	15,648	4.93	591	.299	.067	.084	.450	.268	.182

RESULTS OF PLANT TESTS.

The following data concerning the use of coal from Perry County, district 6, seam 6, when used with Eastern gas coal, were furnished by Mr. Edward H. Taylor, fuel and gas engineer. They are the average results of several days' operation at the plants given. The figures in the last column represent the product of the yield of gas per pound of coal and the heating value of the gas per cubic foot. This product gives the thermal value of the gas obtained from 1 pound of coal, and furnishes a good basis for comparing results:

TABLE 7.—*Results of using in different gas plants one-third Illinois coal and two-thirds Eastern gas coal.*

Situation of gas plant.[a]	H_2S in gas at outlet of exhauster.	H_2S in gas at outlet of scrubbers.	Total sulphur in purified gas.	Yield of gas per pound of coal.	Heating value of gas per cubic foot, B. t. u.	Heating value of gas per pound of coal, B. t. u.
	Grains per 100 cubic feet.	*Grains per 100 cubic feet.*	*Grains per 100 cubic feet.*	*Cubic feet.*		
Cairo	330	240	13.2	4.5	615	2,767
Champaign	390	275	11.9	4.6	608	2,997
Decatur	......	......	16.3	5.22	578	3,016
De Kalb	280	210	9.9	5.0	591	2,955
Dixon	310	270	......	4.9	575	2,818
Jacksonville	280	270	15.0	5.01	625	3,131
Kankakee	270	200	17.2	4.9	606	2,969
Mattoon	180	150	11.2	4.6	598	2,751
Mendota	......	......	......	5.0	......	......
Pontiac	230	180	10.3	4.6	609	2,801
Sterling	260	190	......	5.01	590	2,956
Clinton	......	......	......	4.8	......	......
Galesburg	300	210	10.2	4.73	603	2,852
La Salle	......	......	......	4.41	596	2,628
Canton	400	220	14.8	5.06	595	3,011
Quincy	240	190	10.0	5.17	580	2,999
Freeport[b]	303	......	8.6	5.24	598	3,134
Alton	402	388	11.2	5.3	595	3,153

[a] All situated in Illinois.

[b] At this plant one-fourth instead of one-third Illinois coal was used.

WATER GAS FROM ILLINOIS COAL.

A gas company in East St. Louis is using Illinois coal for manufacturing water gas. Run-of-mine coal, instead of coke, is charged to the generators. The company is making about 1,000,000 feet of gas per day by this method, and reports satisfactory results. Approximately 37 pounds of coal is used per 1,000 feet of gas, and the gas obtained is reported to have a heating value about 75 B. t. u. per per cubic foot higher than that from coke. The coal used is from Jackson County, district 2, seam 2.

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